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DEPARTMENT OF TRANSPORTATION

DIVISION OF NEW TECHNOLOGY, MATERIALS AND RESEARCH

OFFICE OF STRUCTURAL MATERIALS

EFFECTS OF CORROSION ON THE BARE WEATHERING STEEL IN THE ANTIOCH BRIDGE

FINAL REPORT # FHWA/CA/TL-93/09

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16. ABSTRACT

Visual assessments of the appearance of the steel were made at the inception, during and at the end of this project. The steel surfaces at the beginning of the project appeared to be flaking and some areas such as the underside of flanges and web areas near the top flange are still flaking. Relative humidity monitored over a year's time showed that the R.H. was 50% and greater 60% of the time. Pit depth measurements on test plaques placed on the bridge showed an pit depth growth rate of over 0.3 mils / year and the bridge components measured had rates approaching the 0.3 mils / year rate that was established in NCHRP 314 as an acceptable upper limit for pit depth growth rate. Micrometer and ultrasonic thickness measurements at 3.25, 8, 10, and 14 years yield an approximate flat curve after the initial loss from the first measurements. The thickness measurements however, were predominantly greater than the design thicknesses. Rust samples and tests on the steel surface showed the continuous presence of chlorides. Air monitoring over a 33 consecutive day period showed no significant pollutant level. Monitoring of the chlorides in the San Joaquin River showed that the chloride content of the river in the vicinity of the bridge during periods of drought and low fresh water flow was 18 to 25% of the chloride content of sea water. Recommendation is made to remedially paint or continue to monitor the San Joaquin River Bridge at Antioch, California.

17. KEY WORDS

weathering, steel, corrosion, atmospheric

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40	millimetres (mm)
		0.02540	metres (m)
	feet (ft) or (')	0.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.452×10^{-4}	square metres (m^2)
	square feet (ft^2)	0.09290	square metres (m^2)
	acres	0.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	0.02832	cubic metres (m^3)
	cubic yards (yd^3)	0.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	0.06309	litres per second (l/s)
Mass	pounds (lb)	0.4536	kilograms (kg)
Velocity	miles per hour (mph)	0.4470	metres per second (m/s)
	feet per second (fps)	0.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	0.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	pounds per cubic foot (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb)	4.448	newtons (N)
	kips (1000 lb)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lb)	0.1130	newton-metres (Nm)
	foot-pounds (ft-lb)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration (mg/kg)	parts per million (ppm)	1	milligrams per kilogram

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EFFECTS OF CORROSION ON THE BARE WEATHERING STEEL IN THE ANTIOCH BRIDGE

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1. INTRODUCTION

1.1 PROBLEM

The San Joaquin River Bridge at Antioch California was fabricated out of ASTM A588 weathering steel. Weathering steel is steel that because of it's alloy composition and under proper conditions forms a hard tight rust that protects the underlying steel from further corrosion.
Four years after erection, Caltrans engineers noted that in some areas, the rust coat on the steel girders was flaking off. This condition indicated that the weathering steel may not be forming the stable protective coat. If this was the case, the steel would continue to corrode and have an unacceptable loss of section.

1.2 OBJECTIVES

1.2.1 Determine if the ASTM A588 weathering steel in the San Joaquin River Bridge is performing as expected and if not discover and document the factors contributing to the adverse performance.

1.2.2 Determine if corrective action needs to be taken and what degree of corrective action will maintain the structural integrity of the bridge.

2. BACKGROUND

Metallurgists qualitatively understood the effects of small alloy additions on the atmospheric corrosion resistance of structural steel by 1900. The first quantitative research on the enhancement of steel's corrosion resistance by small additions of nickel was reported in 1901. The first quantitative research on the effects of combined additions of copper and nickel to steel was reported in 1910, in 1913 for copper additions, in 1924 for small chromium additions and in 1929 for phosphorus additions.

The first experimental plates of weathering steel were placed in service by International Nickel Company in 1932. By 1940 Bethlehem Steel Company was marketing Mayari R weathering steel made from chrome-nickel bearing iron ore from their mines in Mayari, Cuba and U.S. Steel was marketing Corten weathering steel. It was, however, 1945 before research began to uncover the mechanisms by which these

alloy additions enhance the corrosion resistance of weathering steel. This information eventually enabled metallurgists to refine the early weathering steel alloys and to develop new weathering steels for special purposes (i.e., welding as in A588 steel). The corrosion resistance of these steels was alleged to be four to six times that of mild carbon steel, and the corrosion rate would become negligible after the outer layer of steel had formed a stable coat of rust sometimes called a "patina".
This was a great advancement for steel construction. It permitted steel structures to be fabricated without the expensive initial painting and subsequent maintenance paintings. It has been estimated that the initial painting of the Antioch Bridge would have cost 1.3 million dollars.

Soon other steel companies began producing their own versions of weathering steel. These steels, were, however, issued with cautions as to local environment, handling, preparation, and design details that were a prerequisite for the weathering steel to form the stable protective coat.

Designers in many states and abroad soon began specifying these weathering steels for economic and aesthetic reasons (1,2,3,4). Michigan, for instance, constructed approximately 500 unpainted weathering steel bridges during the period 1965 through 1979.

Michigan monitored their bridges and found that in some bridge components, corrosion rates did not decrease but actively continued. The heavy use of deicing salt was one of the primary causes.

In 1979, Michigan called a moritorium on the construction of weathering steel bridges and began corrective maintenance by sandblasting and painting. A new problem arose, however, with the appearance of a "green mold" a few hours after sandblasting. This phenomenon was apparently caused by chlorides embedded in the steel. Another problem was the greater effort required to remove the rust from weathering steel. The steel Structures Painting Council and others began seeking a solution to this problem (5).

Other laboratories, such as the Transport and Road Research Laboratory of England, have conducted extensive research on unpainted weathering steel. One of these reports, TRRL 857, compared sheltered versus open conditions and found that the open type tests were not applicable to steel sheltered by a bridge deck (6,7).

In 1982, the American Iron and Steel Institute (AISI), an organization composed of members of industry and public officials, published a report in which they acknowledged that there was a problem but indicated that it was confined to areas such as leaky expansion joints and low clearance bridges. Members of this organization inspected 49 bridges in seven states and found that 12 percent had areas of heavy corrosion (8).

In 1983, the University of Maryland published a report "Fatigue Design Stresses For Weathering Steel Bridges" that concludes that pitting, mill scale, rusting, etc... reduces the fatigue life of unpainted weathering steel bridges and recommends that the AASHTO allowable fatigue stresses be proportionately reduced. (9). John Barsom of U.S. Steel, author of many research papers on fracture mechanics and fatigue, feels that the reduction in fatigue life due to weathering is no greater than that caused by welding details commonly used in bridge fabrication (10).

More recently, John Fisher has concluded that allowable fatigue stresses for categorys D and higher should be reduced for pitted weathering steel but that the allowables for categorys E and E′ are sufficiently conservative and need not be reduced.

The San Joaquin River Bridge at Antioch California is a 1.8 mile long structure located about 26 miles inland from San Pablo Bay. Unpainted ASTM A588 weathering steel was specified for the superstructure in order to realize substantial savings in both initial painting and maintenance painting costs. Tests and experience had shown that under favorable conditions, this unpainted alloy steel would rust at a steady rate over the first few years of service forming a tight layer of rust described in the literature as a "patina" which would protect the underlying steel and provide a pleasing appearance.

3. CONCLUSIONS

During periods of low rainfall, the San Joaquin River becomes significantly salty at the bridge location.

The girder steel was contaminated with chlorides during fabrication, during shipment and is subject to continued chloride contamination from the San Joaquin River.

The steel girder surface shows the presence of chlorides after high pressure washing.

The average relative humidity in the bridge vicinity is high enough for corrosion to actively continue.

Micrometer and Ultrasonic measurements on ground surfaces show no appreciable loss over a ten year period.

Average pit depth measurements on sample plaques made from ASTM A588 steel sampled during fabrication and A588 steel removed from the bridge are greater than the acceptable range set forth in NCHRP 314.

Atmospheric tests showed no significant pollutants from industrial plants in the vicinity.

4. OBSERVATIONS

The underside of flanges, some web areas near the top flange on the interior sheltered area of the bridge and some panels that were observed to be flaking in the initial appraisal are continuing to flake.

The paint systems consisting of sandblasting and two coats of PWB primer applied in 1983 had rust breakthrough at the end of approximately two years. At ten years, the breakdown of the coating system is progressing at a slow rate.

The paint systems that were applied in 1990 are still being monitered and all but the exception of one are still showing no signs of failure. The inorganic zinc system is showing pinpoint breakthrough at this time.

5. RECOMMENDATIONS

Continue to monitor the bridge and paint systems applied in 1990 and make determination whether to paint at a later date. (Painting at a later date may prove more costly as the pit depths increase.)

Alternative recommendation: Select the most successful paint system proven by field tests and remedially paint the San Joaquin River Bridge using the recommendations of the Chemical Research Development & Quality Assurance Testing Branch of the Office of Research Corrosion, Enviro-Chemical & Graphics of the Division of New Technology, Materials and Research of the California Department of Transportation.

Carefully investigate the site enviromental conditions before deciding to use unpainted weathering steel in a steel structure.

6. Implementation

It is the responsibility of Caltrans Structure Maintenance to implement the recommendations of this report. This report will be forwarded to Structure Design to aid in their decision making for other upainted weathering steel structures.

7. OBJECTIVES

7.1 Objective 1

The primary objective of this project is to determine if the ASTM A588 weathering steel in the Antioch Bridge is performing as expected and if not, discover and document the factors contributing to the adverse performance.

7.2 Objective 2

Surface preparations will be evaluated in combination with coating systems for the purpose of adding to the pool of information on this subject and for the possibility that corrective action need be taken in case the results of the first objective is adverse.

7.3 Plan For Achieving Objectives

Accomplishment of the first objective is by the following methods:

A. Documentation of events and conditions that may be corrosion contributing factors.

B. Measurement of flanges and stiffeners at multiple locations at significant years time intervals with micrometer.

C. Measurement of webs at multiple locations at the same time intervals as the flanges and stiffeners with an ultrasonic thickness gage.

D. Measurement of pit depths on bolts and splice plates removed from the the bridge after a significant number of years of exposure.

E. Visual observations and photographs.

The second objective is accomplished by:

A. Combining sucessful paint systems with varying degees of surface preparation on selected areas of the bridge.

B. Evaluate paint systems applied to varying degrees of surface preparation at significant time intervals.

8. HISTORY OF ENVIRONMENTAL CONDITIONS

8.1 Fabrication

The Antioch Bridge girders were fabricated in three locations in Japan - Kobe, Nagasaki and Nagoya. All three locations are subject to chloride contamination from salt air. However, Nagasaki has the most severe environmental conditions for chloride contamination and high humidity because of its location at the extreme Southern part of Japan which is completely surrounded by sea water. As indicated in figure 1, girders G31 through G43 were fabricated in Nagasaki.

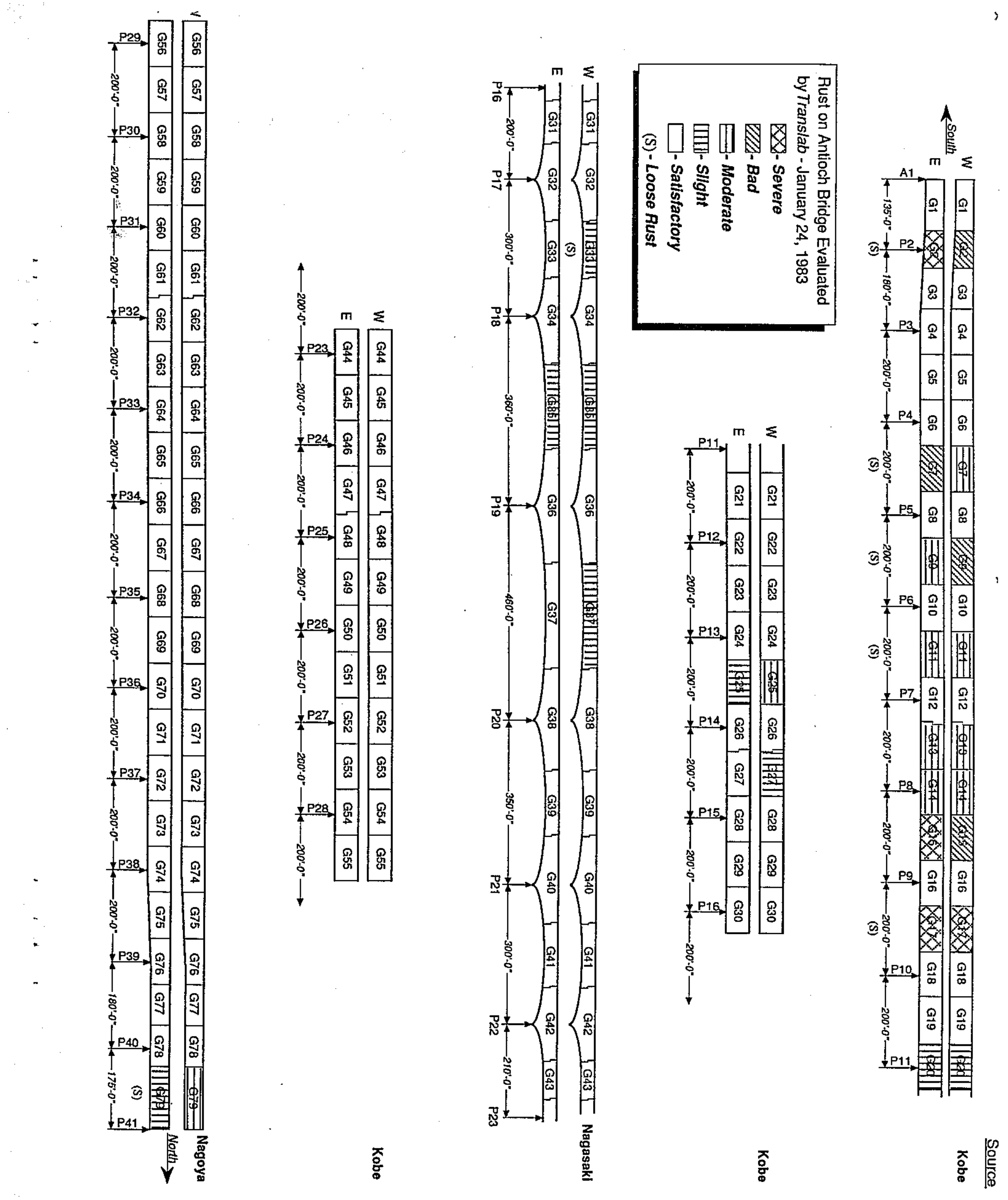

Source
Rust on Antioch Bridge Evaluated by Translab - January 24, 1983
- Severe
- Bad
- Moderate
- Slight
- Satisfactory
(S) - Loose Rust
South
North
Kobe
Nagasaki
Nagoya

Figure 1

8.2 Shipping

Contract records were searched, the project engineer and inspectors were interviewed, and Mitsubishi Heavy Industries of Japan was contacted concerning the shipment of structural steel for the Antioch Bridge.

All girders were shipped across the ocean. Some were shipped on deck and some were shipped below deck. The following is a listing of which girders were shipped on deck and subjected to salt water spray and which girders were shipped below deck and thus protected from salt spray.

SHIPPED ON DECK AND EXPOSED TO SALT SPRAY

WG2	EG2	WG3	EG3	WG5	EG5
WG7	EG7	WG9	EG9	WG11	EG11
WG12	EG12	WG13	EG13	WG14	EG14
WG15	EG15	WG16	EG16	WG17	EG17
WG18	EG18	WG19	EG19	WG31	EG31
WG32	EG32	WG33	EG33	WG34	EG34
WG35	EG35	WG36	EG36	WG37	EG37
WG38	EG38	WG39	EG39	WG40	EG40
WG41	EG41	WG42	EG42	WG43	EG43
WG47	EG47	WG61	EG61	WG62	EG62
WG63	EG63	WG70	EG70	WG71	EG71
WG72	EG72	WG73	EG73	WG74	EG74
WG75	EG75	WG76	EG76	WG77	EG77
WG78	EG78	WG79	EG79		

Table 1

GIRDERS SHIPPED IN THE HOLD - PROTECTED FROM SALT SPRAY

WG1	EG1	WG4	EG4	WG6	EG6
WG8	EG8	WG10	EG10	WG44	EG44
WG45	EG45	WG46	EG46	WG48	EG48
WG49	EG49	WG50	EG50	WG51	EG51
WG52	EG52	WG53	EG53	WG54	EG54
WG55	EG55	WG56	EG56	WG57	EG57
WG58	EG58	WG59	EG59	WG60	EG60
WG64	EG64	WG65	EG65	EG66	EG66
WG67	EG67	WG68	EG68	WG69	EG69

Table 2

It was not possible to determine from the records whether the following girders were shipped in the hold or on deck.

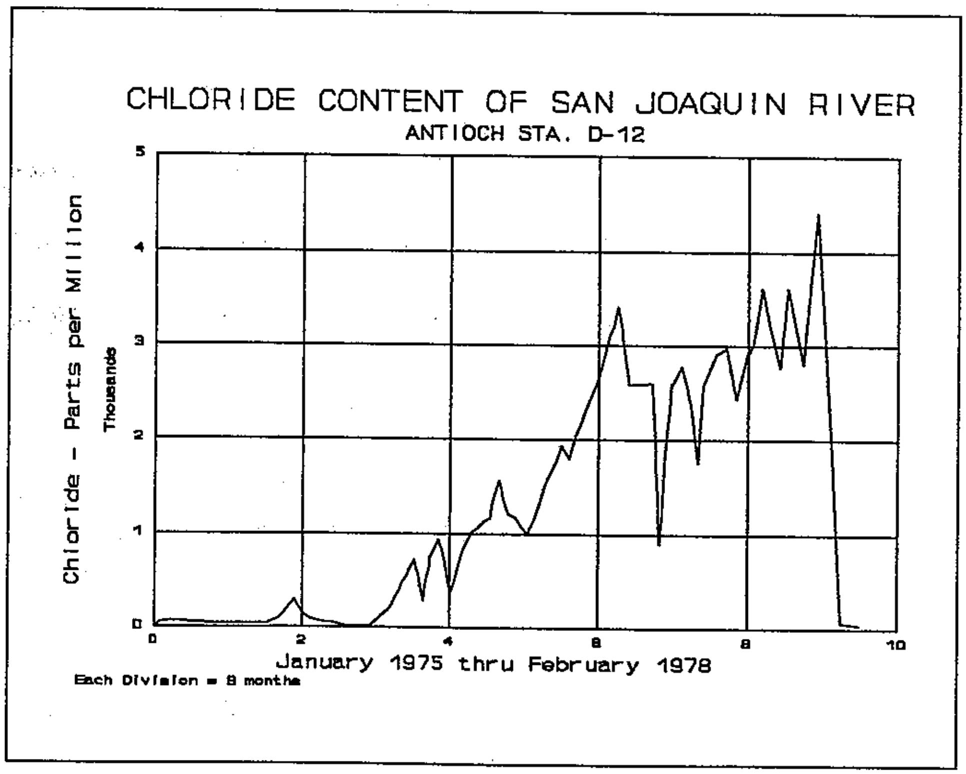
WG20	EG20	WG21	EG21	WG22	EG22
WG23	EG23	WG24	EG24	WG25	EG25
WG26	EG26	WG27	EG27	WG28	EG28
WG29	EG29	WG30	EG30		

Table 3

8.3 Salt Intrusion In The San Joaquin River

At the time the Antioch Bridge was being erected, California was nearing the end of a five year drought. It was suspected that because of the drought and the reduced fresh water flow down the river that the river was probably high in salt content.

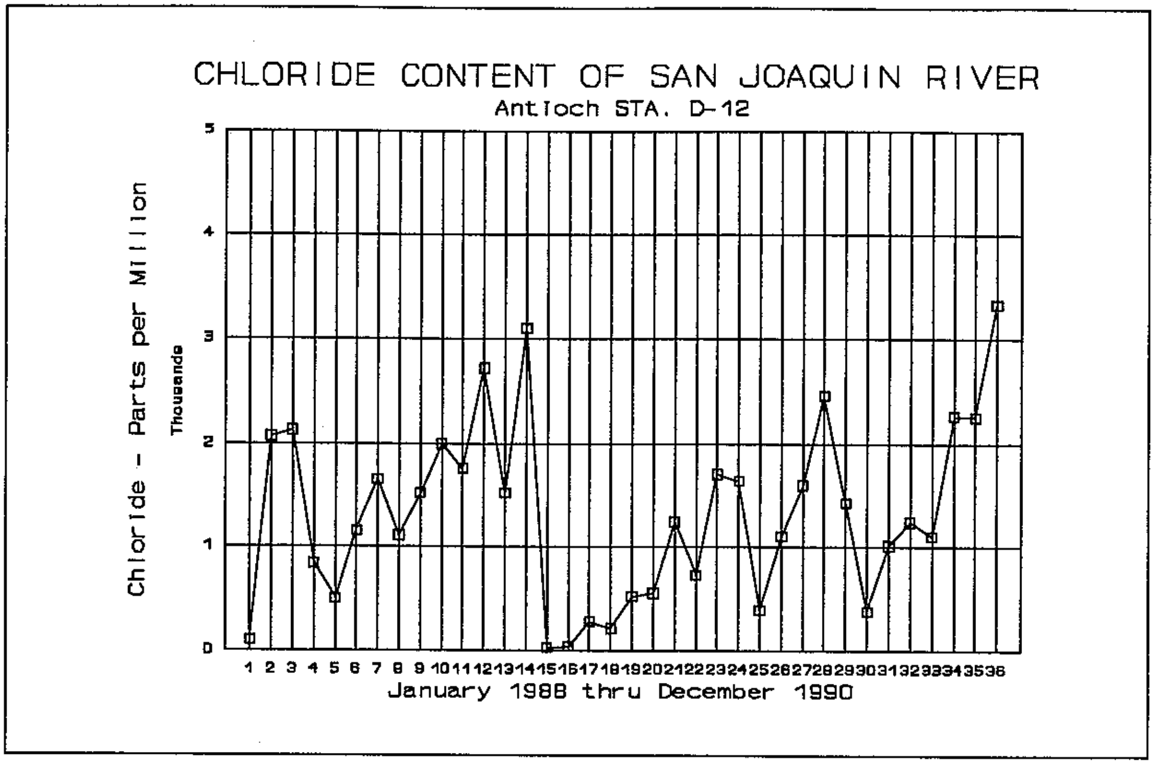
The following graph of the river salinity shows that this suspicion was well founded.



Graph A

*Data from California Department of Water Resources
The chloride content of seawater is approximately 19,000 mg/l. This graph shows that the chloride content of the river at the time of erection was approximately 25% that of seawater.

California is presently in a period of drought of several years duration and the following graph of river salinity shows that during drought periods, the salininity increases significantly during low fresh water flow in winter months.



Graph B

*Data from California Department of Water Resources

This graph shows that the chloride content of the river water at the end of 1990 was approximately 18% of the chloride content of sea water.

8.4 Air Quality

The presence of a paper processing plant approximately one half mile to the West of the South end of the bridge and a chemical plant approximately one fourth mile East of the South end of the bridge gave rise to the possibility of harmful chemical pollutants which may inhibit the weathering steel from performing properly. An air quality test was performed by the Enviro-Chemical Branch of the California Department of Transportation Laboritory. The following is a copy of the results reported by the E.C. Branch:

Per your request, the air Quality, Noise and Vibration Section conducted an air monitoring study at the Antioch Bridge from December 5, 1985 to January 8, 1986.

A mobile lab was set up at the Antioch Bridge Toll Plaza approximately 300 feet from the South end of the bridge structure. Air was drawn into the system from a height of about 15 feet and routed to each continuously running analyzer. Analysis was performed for sulfur dioxide (SO_2), nitrogen dioxide (NO_2), nitric oxide (NO), ozone (O_3) and hydrocarbons (HC) corrected for methane. Wind speed, wind direction and wind direction standard deviation were monitered also. All data were collected and recorded on magnetic tape as 1-hour and 24-hour average concentrations using a SumX data logging system. A hi-vol sampler was used to collect aerosol samples on 3 days (December 14, 17 and 20, 1985).

Air monitoring of gaseous pollutants was conducted for 33 consecutive days. Following is a table showing the highest 1-hour average concentration measured for each gaseous pollutant and the highest 24-hour average concentration of sulfate (SO_4) aerosol:

POLLUTANT	HIGHEST 1-HOUR AVG.CONC	DATE OF OCCURANCE	HOUR OF OCCURANCE	AMBIENT AIR QUALITY STANDARD
SO_2	0.010 PPM	12-06-85	1500-1600	0.250 PPM
SO_2	0.010 PPM	01-01-86	1200-1300	0.250 PPM
NO_2	0.059 PPM	12-13-85	0500-0600	0.250 PPM
NO	0.159 PPM	01-08-86	1900-2000	-----
O_3	0.050 PPM	12-14-85	1400-1500	0.012 PPM
HC	0.9 PPM	12-15-85	0200-0300	-----
SO_4	4.7 ug/m^3	(24 hour average)		25 ug/m^3

Table 4

All measured concentrations are below the National and State Ambient Air Quality Standards. The Ambient Air Quality standards are established to protect the health of the very young, the very old and the infirm. Using these standards as a basis for comparison, and effect on the oxidation rate of the steel under the bridge by the above pollutants should be negligible.

Wind direction during the study period was predominately ESE. Hourly average wind direction, when grouped by quadrant and expressed as percent of the study period, was distributed as follows:

North 15% East 67% South 6% West 12%

Hourly average wind speed was distributed as follows:

0 - 3 MPH 30% 4 - 7 MPH 52% 8 - 12 MPH 11% 13 MPH+ 7%

The monitoring took place approximately 300 feet south of the bridge structure.

however it is felt that the air quality directly under the bridge would not be significantly different.

8.5 Relative Humidity

Relative humidity measurements were supplied by the California Air Resources Board for one years time period (1990) from their monitoring station at Pittsburg, California. Pittsburg, California is approximately nine miles directly West along the confluence of the San Joaquin and Sacramento rivers from the Antioch Bridge.

During the time period 1/1/90 to 1/1/91, the average relative humidity was above 50% 60% of the time.

9. MEASUREMENTS

9.1 Micrometer Measurement Of Flanges And Stiffeners

Bottom flanges and vertical stiffeners in span 2, pier 2, pier 6, pier 8, pier 11, pier 16, and pier 17 were measured with micrometers at 3.25, 8, 10, and 14 years from erection of the bridge. see figure 1.

Sites were selected that were accessible from the pier via catwalk or from a lift truck at the lower southern end of the bridge. The majority of the locations were in the sheltered interior surfaces of the girders.

Two inch by four inch strips on opposing surfaces of the flanges and stiffeners were ground to remove rust from the base metal with a rotary grinder (sidewinder). Care was taken to avoid removing base metal.

Five measurements were taken along the ground strips with a micrometer which read to 0.001 inch. By estimating the fourth digit, the readings were to 0.0001 inch. After averaging, the result was rounded to the nearest 0.001 inch. Subsequent measurements were taken at adjacent strips prepared in a like manner.

In addition to the stiffeners and flanges accessed from the catwalk and lift truck, measurements were made via a snooper on spans 9 and 18. Because lane closures were necessary for these measurements with the snooper, measurements were only made at two time intervals of 7 and 14 years.

9.2 Ultrasonic Thickness Gage Measurements Of Girder Webs

Girder webs were measured at the same spans and piers where the flanges and stiffeners were measured.

Circular areas approximately 4 inch in diameter were ground to remove rust, taking care to remove a minimum of base metal. Five measurements were taken within the ground area. The ultrasonic thickness gage used gave measurements to the nearest 0.001 inch. Before taking the measurements, the ultrasonic thickness gage was calibrated on a reference block made from a sample of the A588 steel taken during fabrication of the girders. After the measurements were taken, the ground area was coated with a corrosion inhibitor so that subsequent measurements could be made at the same location to measure corrosion progress on the opposite side.

9.3 Corrosion Monitering With Plaques Made From Samples Of A588

Plaques of A588 flange sampled during fabrication of the Antioch Bridge were machined to approximately 4x4x¼ inch. The plaques were machined so that the original surface was left intact on one side. Three samples representing three different heats were used to fabricate 8 plaques each. Two racks were fabricated to hold twelve plaques each. The plaques were supported in the racks by ceramic insulators to prevent galvanic corrosion resulting from contact with dissimilar materials.
One rack was placed on pier 2 and the other on pier 8. Before placing the plaques on the racks, they were blasted to a white metal finish, weighed to the nearest gram and measured with a micrometer at four locations to the nearest 0.0001 inch (fourth digit

estimated).

Plaques were removed at 1 year 4 months, 2 year 10 months, 6 year 1 month, cleaned, reweighed, and remeasured.

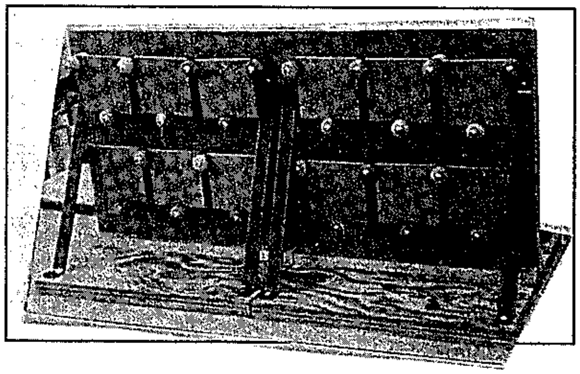


Figure 2

Racks With ASTM A588 Steel Samples

9.4 Bolts Removed From Stiffener Splice Plates

In April, 1989, approximately twelve years after erection, splice plates and bolts for the longitudinal stiffeners were removed from span 2. The bolts and splice plates were cleaned and pit depth measurements taken. Before replacing the splice plates, the faying surfaces were examined to see if crevice corrosion was taking place and the extent of pitting.

10. VISUAL OBSERVATIONS AND PHOTOGRAPHS

Visual observations were made on the appearance of the steel surface on the initial visit and again when visits were made for measurements, application of paint systems and removal of stiffener plates and bolts. Photographs were also taken initially and at several other time intervals.

11. APPLICATIONS OF TRIAL PAINT SYSTEMS

11.1 Coating Systems Applied In 1983

In April, 1983, two sections of webs on the interior side at pier 2 at the south end of the bridge were sandblasted to a white metal finish. Additionally, one panel was given a commercial blast cleaning and another panel was given a wire brush cleaning. One panel given a white metal sandblasting and the one panel given a commercial blast cleaning were given two coats of PWB 80 water born primer. One panel given a white metal blast treatment and the wire brushed panel were not painted and were to be observed later for rust condition i.e. if a tight rust would form.

11.2 Coating Systems Applied In 1990

In September, 1990, Several different paint systems were applied over different cleaning efforts. The following is the test plan prepared by the Chemical Research Development & Quality Assurance Testing Branch of the Office of Research, Corrosion, Enviro-Chemical & Graphics of the Division of New Technology, Materials and Research of the California Department of Transportation.

11.2.1 Primer Systems:

1) Inorganic Zinc - High ratio Potassium Silicate type
2) Vinyl acrylic - PWB-145 and PMB-146
3) Phenolic/Tung Oil - PB-201 and PB-202

11.2.2 Preparation:

Reports from the literature indicate that abrasive blasting a salt-contaminated surface may drive a portion of the salt into the intergranular structure of the steel. The presence of this of this salt will adversely affect the performance of any coating system applied to the steel. Consequently, it is important to remove soluble salts to the greatest degree practically possible prior to the final blasting operation. High-pressure water washing with hot water should remove most of the soluble salts, but it may be necessary to whip-blast the surface in order to permit complete penetration of water into the rust so that the chlorides can be removed. The chloride level in the rust should be evaluated to determine if whip-blasting prior to water washing makes a significant difference. The results of this determination can then be incorporated into the cleaning procedures used for the three primer systems as the first one or two steps. The following additional procedures are recommended for each of the primer systems:

1) Inorganic zinc:

a) Permit the surface to dry and abrasive blast to a near-white condition.

2) Vinyl acrylic:

a) Permit the surface to dry and abrasive blast to a near-white condition.

b) Permit the surface to dry and abrasive blast to a commercial condition.

3) Phenolic/Tung oil

a) Permit the surface to dry and abrasive blast to a near-white condition.

b) Permit the surface to dry and abrasive blast to a commercial condition.

c) Permit the surface to dry and whip-blast.

Table 5 shows these variations

PROPOSED PAINTING TESTS ON THE ANTIOCH BRIDGE

PARAMETERS	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6
CLEANING PROCEDURE						
WASH	X	X		X		
WHIP-BLAST	X		X	X	X	X
WASH	X		X	X	X	X
COMMERCIAL BLAST				X	X	
NEAR-WHITE BLAST	X	X	X			X
1ST PRIME COAT MILS	ZINC 4	ZINC 4	ZINC 4	PWB-145 2	PWB-145 2	PWB-145 2
2ND PRIME COAT MILS	NONE NA	NONE NA	NONE NA	PWB-146 2	PWB-146 2	PWB-146 2

PARAMETERS	TEST 7	TEST 8	TEST 9	TEST 10	TEST 11
CLEANING PROCEDURE					
WASH		X			X
WHIP BLAST		X	X	X	X
WASH	X	X	X	X	
COMMERCIAL BLAST	X	X		X	
NEAR WHITE BLAST			X		
1st PRIME COAT MILS	PWB-145 2	PB-201 2	PB-201 2	PB-201 2	PB-201 2
2nd PRIME COAT MILS	PWB-146 2	PB-202 2	PB-202 2	PB-202 2	PB-202 2

Table 5

If field tests for chloride before the second wash on TEST 1 are positive, then TESTS 2, 7 and 11 will be eliminated.

12. DISCUSSION OF MEASUREMENTS

12.1 Micrometer

Micrometer measurements of 39 flange and stiffener locations are plotted and are presented in appendix A. The measurements as can be seen in the graphs, are generally flat and are not indicative of a great section loss during the monitoring period. Initial and subsequent measurements of the flanges and stiffeners indicate that the existing sections are considerably greater than the nominal section shown in the plans. Grouping the measured locations by the amount the nominal thickness is exceeded is as shown in table 6.

Nominal thickness exceeded by Mils	< 5	5-9	10-19	20-29	30-39	40-49	> 49
Locations	3	1	12	7	8	3	5

Table 6

Although the micrometer measurements are substantially greater than the required nominal thickness, the measurements do not indicate loss from pitting as the micrometer measures the high points.

12.2 Ultrasonic

Ultrasonic measurements of 13 web locations are plotted and are presented in appendix B. These measurements show a greater drop in thickness from the initial measurement than do the micrometer measurements. The reason for the greater difference is that the ultrasonic thickness gages average the thickness over a small area and measure the least thickness. Here again, the measurements are greater than the nominal thickness. The amount that the nominal thickness is exceeded with the ultrasonic measurements is presented in table 7.

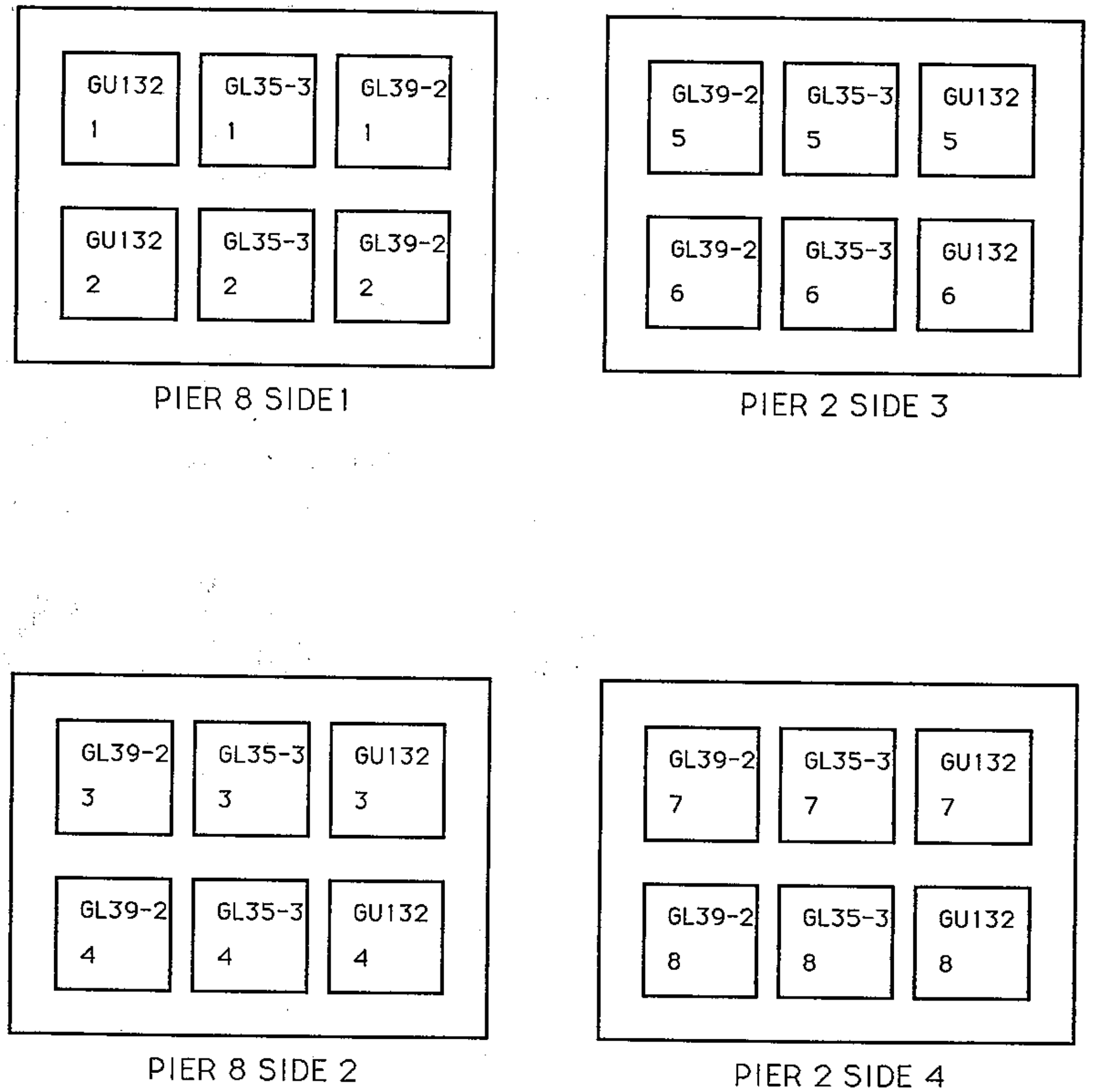
<5	5-9	10-19	20-29	30-39	40-49	>49
1		7	5			

Table 7

12.3 Plaques

12.3.1 Pit Depth and Weight Loss Measurements

Plaque layout on the racks and bridge location is shown in figure 3. The remaining plaques on pier 2 are available for future evaluation. The remaining plaques on pier 8 were destroyed by vandals.



PLAQUE LOCATION ON RACKS AND PIER LOCATION FOR RACKS

Figure 3

After removing the rust from the plaques removed from the two bridge locations, they were weighed to the nearest gram and measurements made with micrometer and depth measuring microscope. The results along with steel chemistries are presented in table 9.

Results of Plaque Measurements

Plaque	Expo. Months	Pit Depth Ave. mils	Pit Depth Max mils	mils/yr Ave.	Thick. Inches*	Init. Wt.gm	Wt.gm After clean	loss gm
GL 39-2-7	61	2.65	4.13	0.52	0.238	478	473	5
GL 35-3-3	16	2.73	3.74	2.05	0.244	485	482	3
GL 35-3-2	33	2.28	3.15	0.83	0.253	511	506	5
GL 35-3-5	16	2.10	3.39	1.58	0.252	506	503.5	2.5
GU 132-1	33	2.73	3.35	0.99	0.231	461	454	7
GL 35-3-7	33	3.58	6.50	1.30	0.252	503	499	4

*Average of 4 measurements

Piece	Sect.	Span	Thick.	Loc.	Chemistry C	Mn	P	S	Si	Ni	Cr	Cu	V
GL39-2	BF	20	2 1/8	WG39	0.11	1.06	0.011	0.007	0.27	0.19	0.45	0.28	0.049
GU132	TF	7	2	EG14	0.11	1.02	0.021	0.006	0.30	0.11	0.52	0.29	0.05
GL35-3	BF	18	2 1/8	WG35	0.11	1.02	0.011	0.007	0.27	0.19	0.45	0.28	0.049

Table 9

The weight loss of removed plaque GL39-2-7 converts to an average section loss of 2 mils over the entire surface. This is approximately 0.52 mils/yr which is outside the acceptable limit established in NCHRP 314.

12.3.2 Maximum Pit Depth By Grinding

Figure 4 is the surface of GL 35-3-3 after grinding off approximately 4 mils. The light areas are pits remaining. It required grinding off 7 mils before all of the pits were ground out indicating a maximum pit depth of 7 mils.

GL 35-3-3 Shows pits Remaining After Removing 4 mils By Grinding

Figure 4

The difference between this maximum pit depth and that obtained by depth measuring microscope is that it is practically impossible to remove all of the rust products from the bottom of the pits.

Figure 5 is a photo of the surface of plaque GL 39-2-7 after grinding off 7 mils. The light areas show remaining pits.

GL 39-2-7 Pits remaining After Grinding Off 7 Mils

Figure 5

12.4 Stiffener Splice Plates and Fasteners

Pit depth measurements

Pit depth measurements were made on a bolt and washer removed along with the stiffener splice plate in 1989. This means that these elements were exposed approximately 12 years as a part of the bridge structure.

The washer shown in figure 6 is pitted around the outer edge and shows little pitting in the area that was under the nut. The average pit depth in the pitted area is 0.0027 inch. This would be approximately 0.22 mils/year.

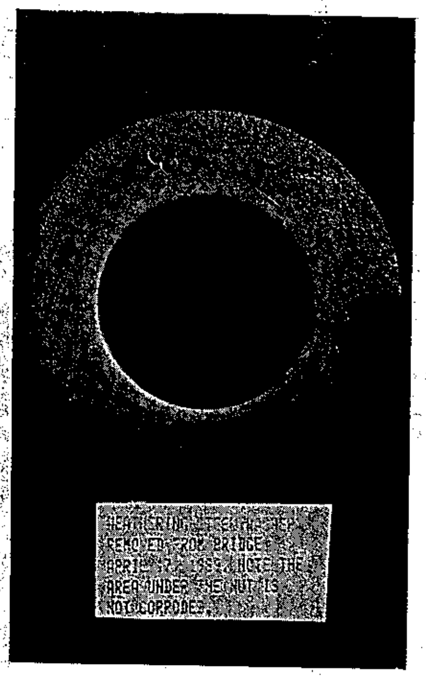


Figure 6

The bolt shown in figure 7 is pitted on the exposed threaded end and had an average pit depth of 0.0033 inch in the pitted area for an average of 0.28 mils/year.

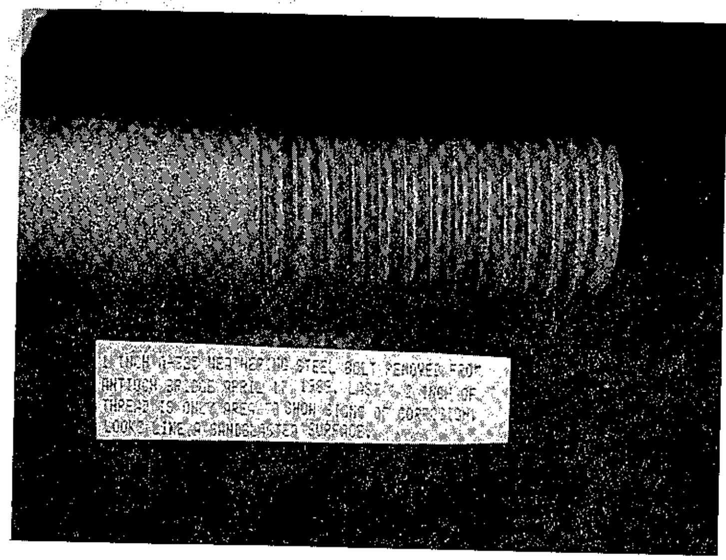


Figure 7

The area where the bent stiffener splice plate and the girder splice plate come together shows active corrosion on both the girder splice plate and the stiffener splice plate. The bent plate provides a recepticle for debris of all kinds which tends to hold moisture. Figure 8 is a view of the girder splice plate with the stiffener splice plate removed.

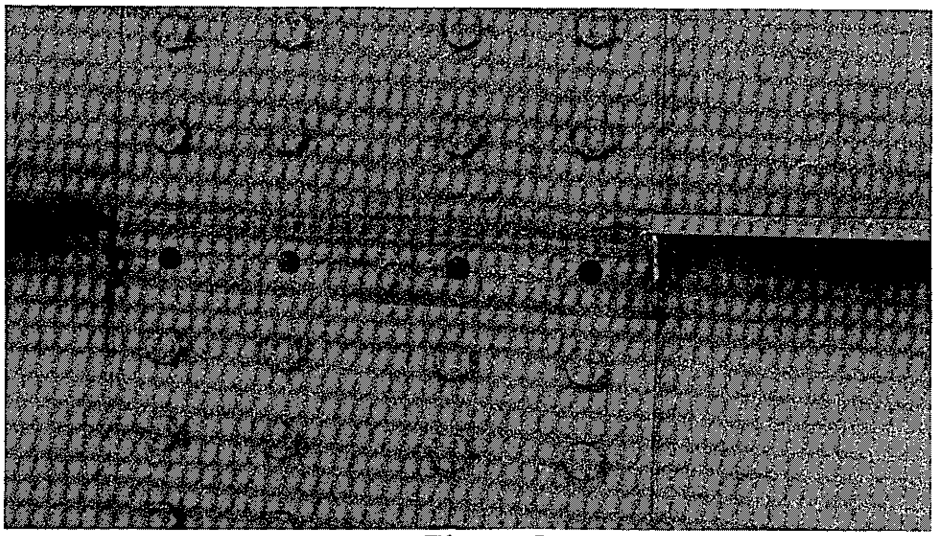


Figure 8

13. DISCUSSION OF ENVIRONMENTAL CONDITIONS

13.1 Chlorides

The steel in the Antioch Bridge was subjected to chloride contamination during fabrication from the proximity of the ocean in Japan, during shipping across the ocean where some of the girders were exposed on deck, and in its final position across the San Joaquin River where the water becomes salty during periods of low fresh water flow. The presence of chlorides has been established by tests on the rust from the girders when the bridge was being erected, during this investigation and from tests performed after sandblasting and high pressure water cleaning.

Because of the near impossibility of removing all of the rust at the bottom of pits by sandblasting and high pressure water washing, it must be assumed that there will continue to be chlorides present after these surface preparations are performed.

13.2 Relative Humidity

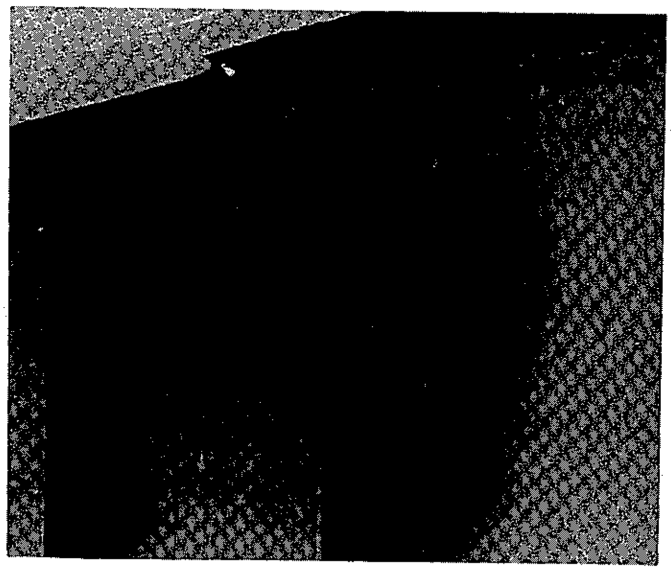
Relative humidity measurements during the year 1990 supplied by The Bay Area Air Quality Management District showed that the relative humidity in the bridge area was greater than 50% 60% of the time. This is high enough to cause active corrosion to take place in a salt laden environment.(12) This data is presented in appendix C.

13.3 Atmospheric Pollutants

Air monitoring which was previously discussed showed no significant pollutants from the industrial plants in the area. A possible explanation for the absence of pollutants is the fact the the prevailing wind during the monitoring was Easterly 67% of the time and the wind speed was greater than 3 mph 70% of the time.

14. VISUAL OBSERVATIONS

Initial observations as indicated in figure 1, were that there were areas that appeared to not be stabilizing. These areas have a good correlation with members that were shipped above deck indicating that the salt contamination from the ocean spray had a significant role in the continuing corrosion. Recent observations reveal that some areas such as the undersides of flanges and corners between top flanges and webs where water condenses are still flaking as can be seen in figure 9.



15. Discussion of Trial Paint Systems

15.1 Coating Systems Applied in 1983

The surface preparations for the PWB primer applied in 1983 were: 1. Commercial blast cleaning. 2. White metal blast treatment. Blasting material was "Green Diamond" slag.

Two coats of PWB 81 were applied initially to each web panel but because of a thin 1st coat, a third coat of PWB 80 was applied about a month later to one half of each panel. Initial breakdown of the surface was observed about 3 years later with more breakthrough showing in the area of two coats. Although there was early breakthrough in the paint system, the continued breakdown has been slow and the system is continuing to provide some protection after 9 years.

15.2 Coating Systems Applied in 1990

With less than two years the systems described earlier in section 10 are showing no breakthrough except the inorganic zinc which is showing a small amount of breakthrough. Caltrans personnel will continue to monitor these systems to determine which are the most effective for remedial painting. Tests 2, 7 and 11 in table 5 were eliminated because tests for chloride were positive before second wash.

16. REFERENCES

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4. Letter and attachments from P. J. Fredrick, Chief Maintenance and Operations Engineer, Louisiana Department of Transportation and Development, May 16, 1983.

5. "Painting of Weathering Steel: A Preliminary Survey," Draft No. 3, Steel Structures Painting Council, January 1983.

6. Mckenzie, M., "The Corrosion Performance of Weathering Steel in Highway Bridges," Transport and Road Research Laboratory Report 857, 1978.

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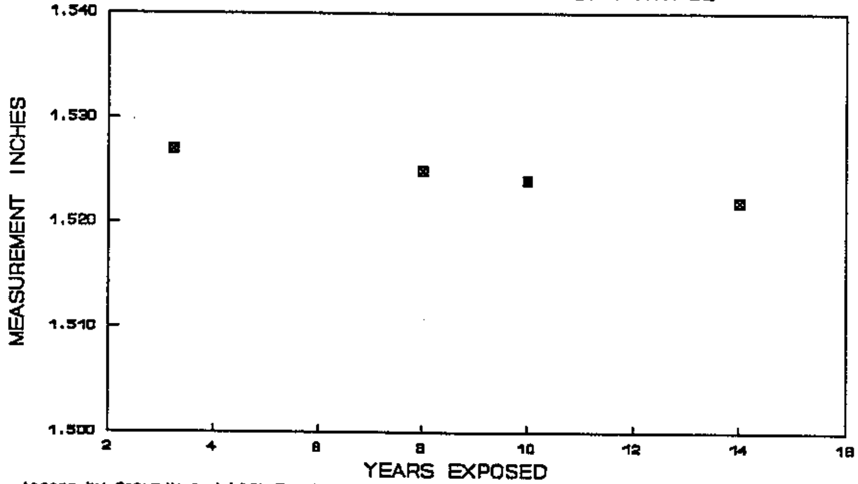
14. "Guidelines For Evaluating Corrosion Effects In Existing Steel Bridges", NCHRP Report 333, J. M. Kulicki, Z. Prucz, D. F. Sorgenfrei and D. R. Mertz, Modjeski and Masters, 1990.

17. APPENDIX A

GRAPHS OF MICROMETER THICKNESS MEASUREMENTS

GRAPH 1

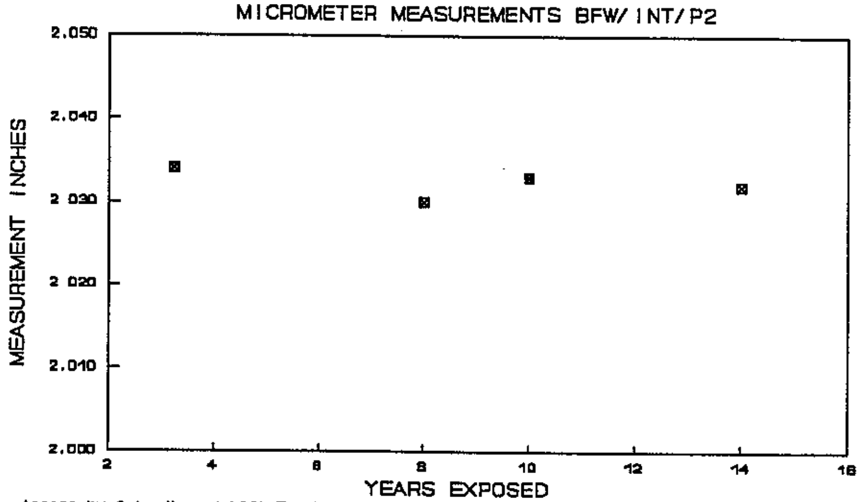
MICROMETER MEASUREMENTS BFW/INT/S2



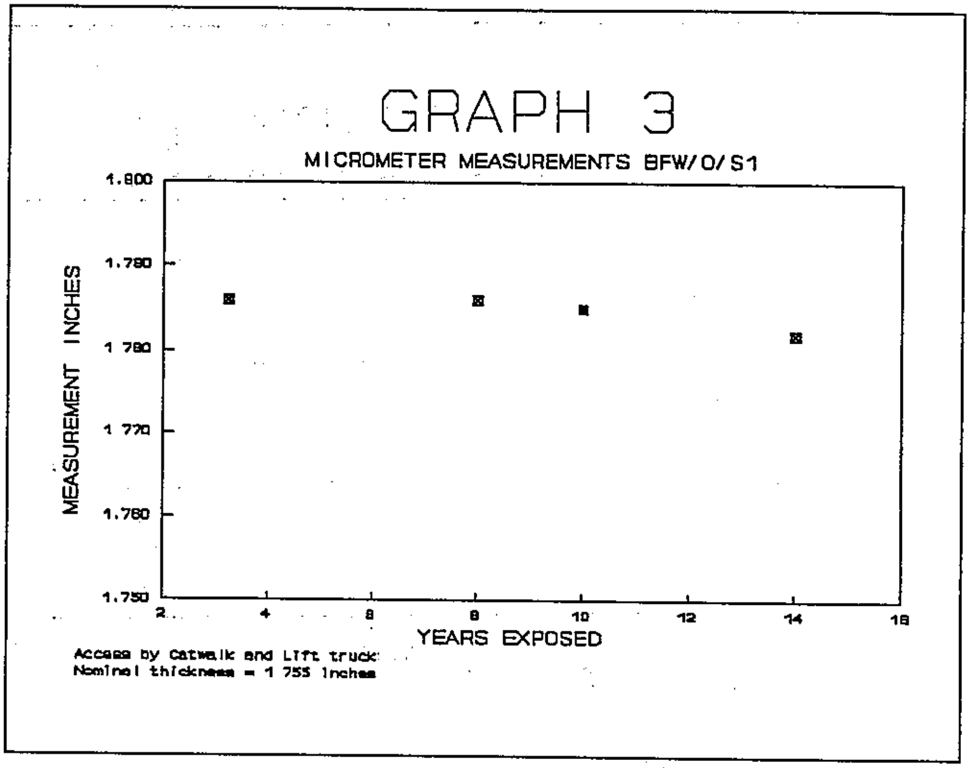
Access by Catwalk and Lift Truck
Nominal thickness = 1 500 inches

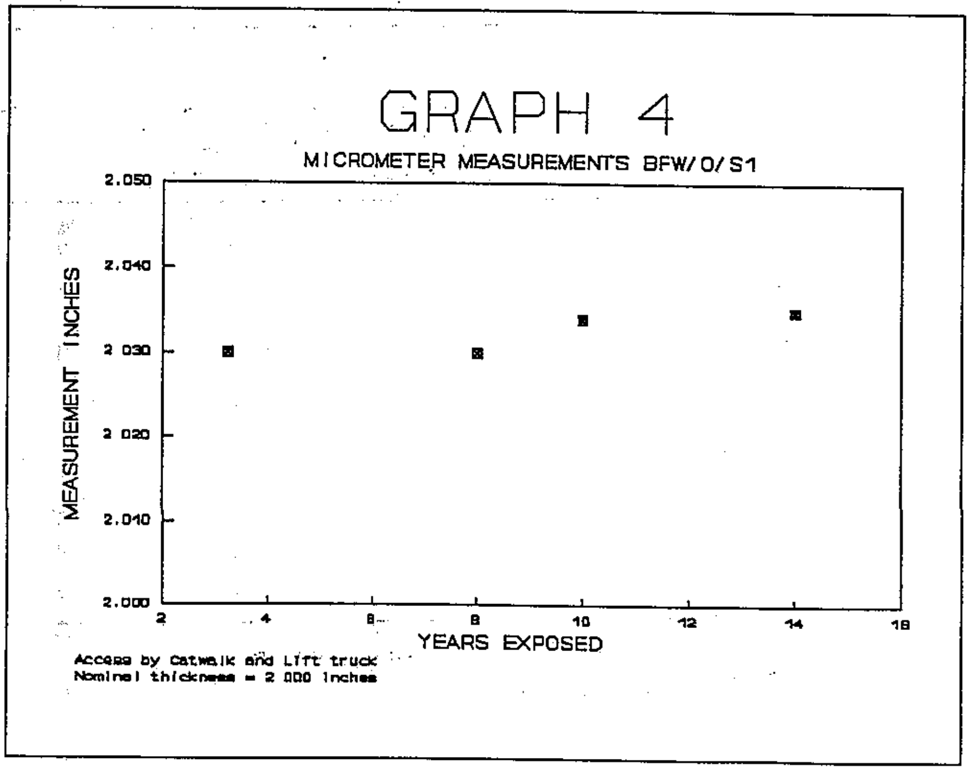
GRAPH 2

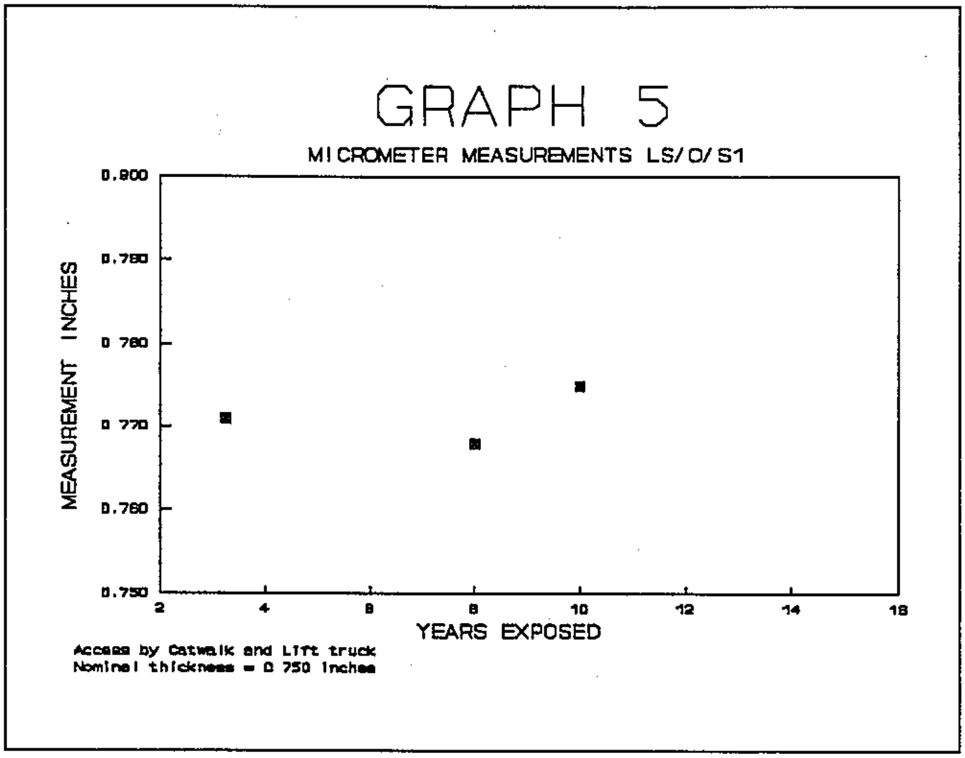
MICROMETER MEASUREMENTS BFW/INT/P2

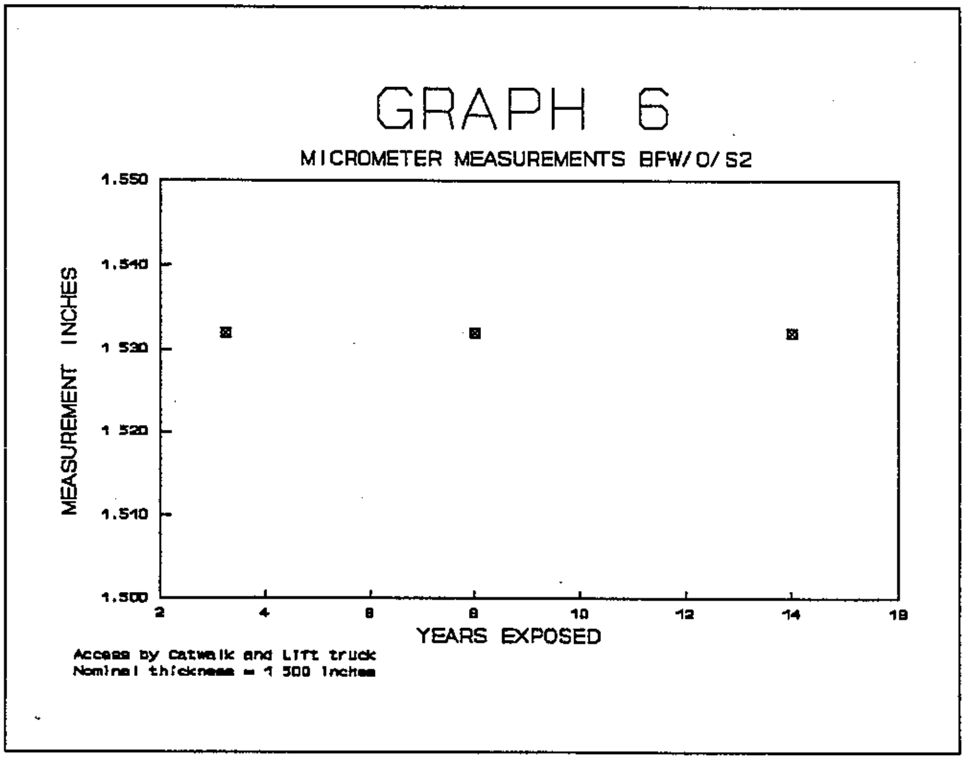


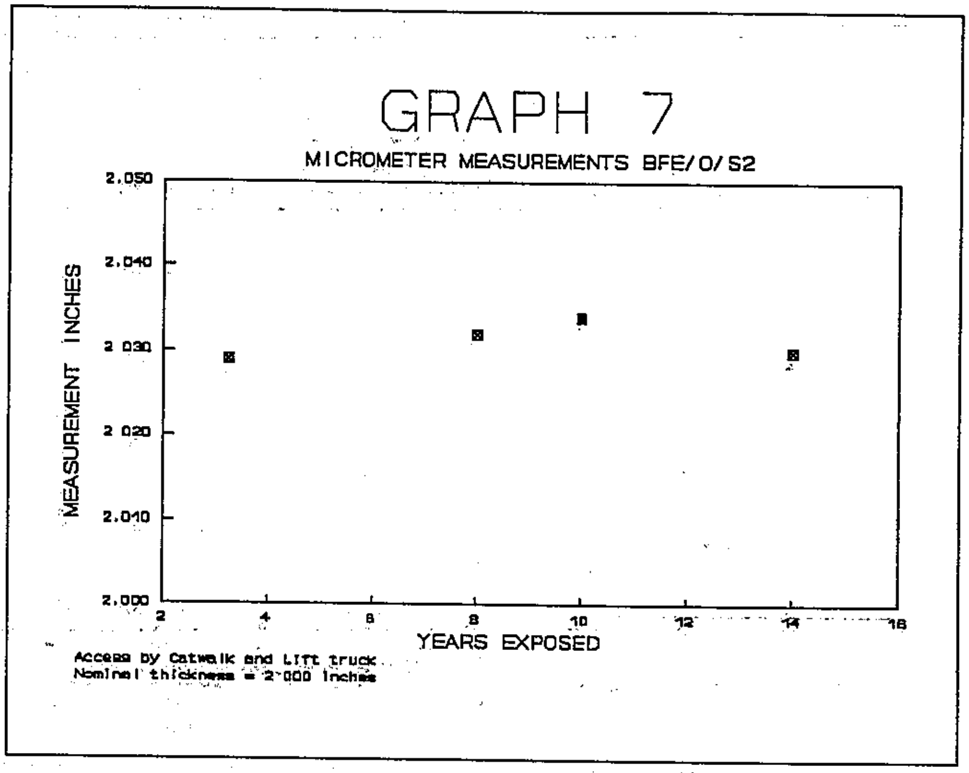
Access by Catwalk and Lift Truck
Nominal thickness = 2 000 inches

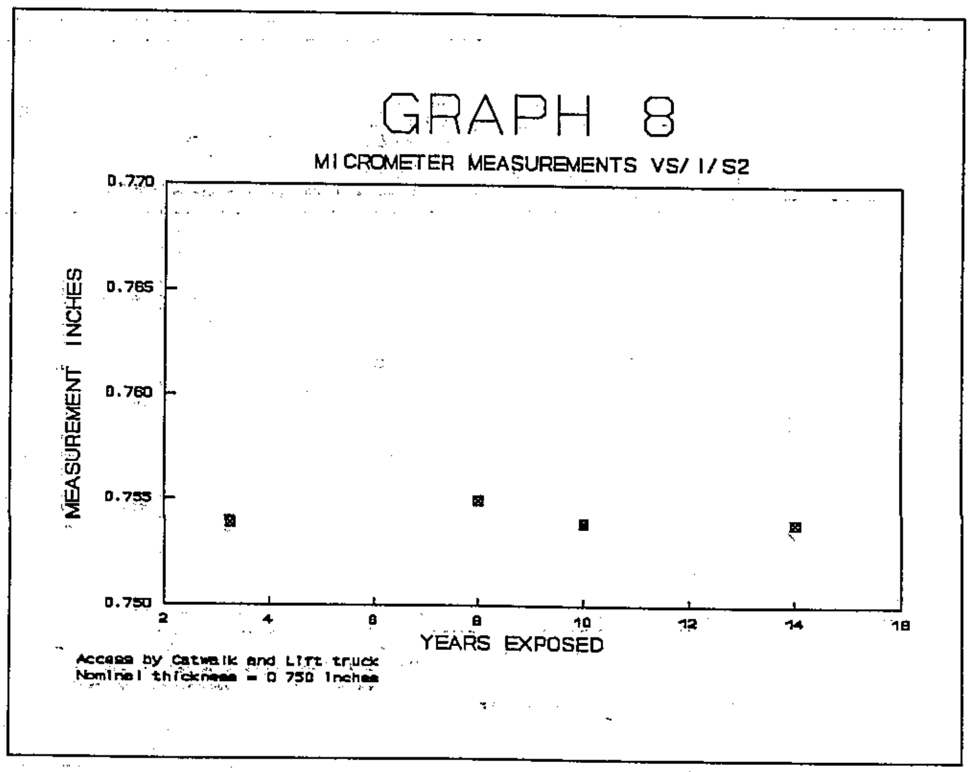

GRAPH 3
MICROMETER MEASUREMENTS BFW/O/S1
MEASUREMENT INCHES
1.800
1.790
1.780
1.770
1.760
1.750
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 1.755 inches

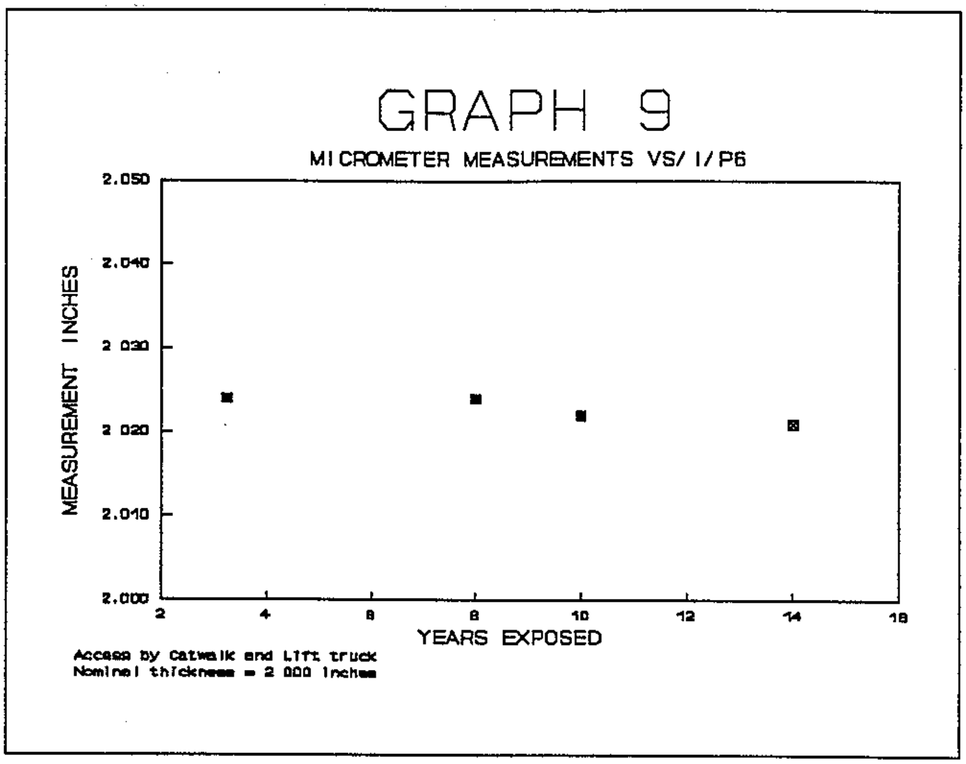

GRAPH 4
MICROMETER MEASUREMENTS BFW/O/S1
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

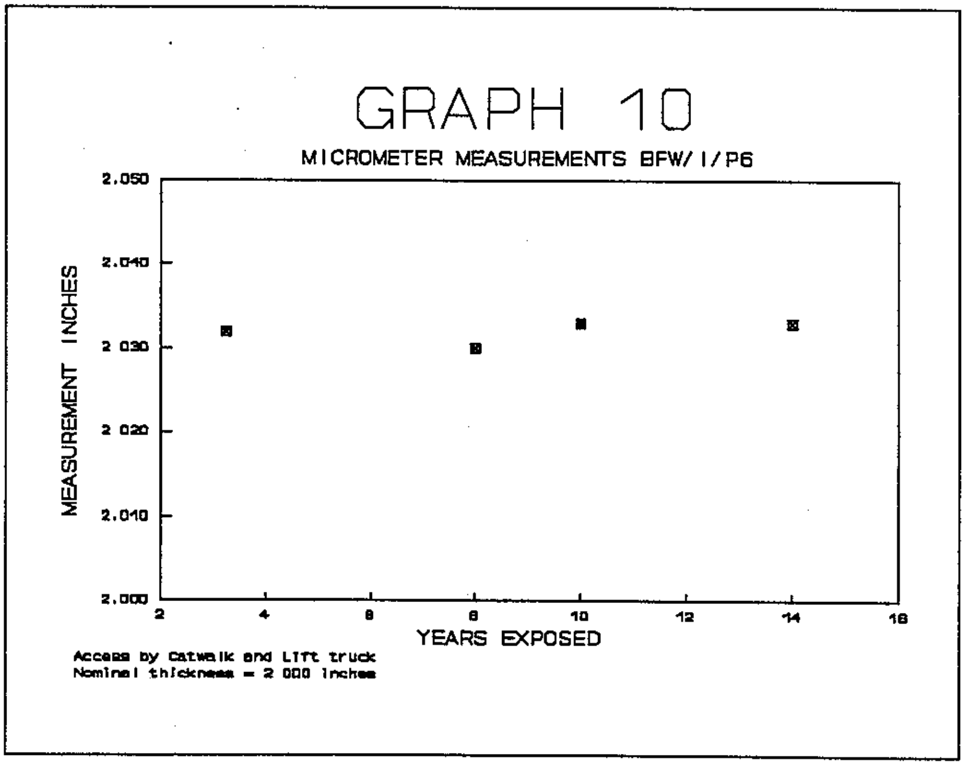

GRAPH 5
MICROMETER MEASUREMENTS LS/O/S1
MEASUREMENT INCHES
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.750 inches

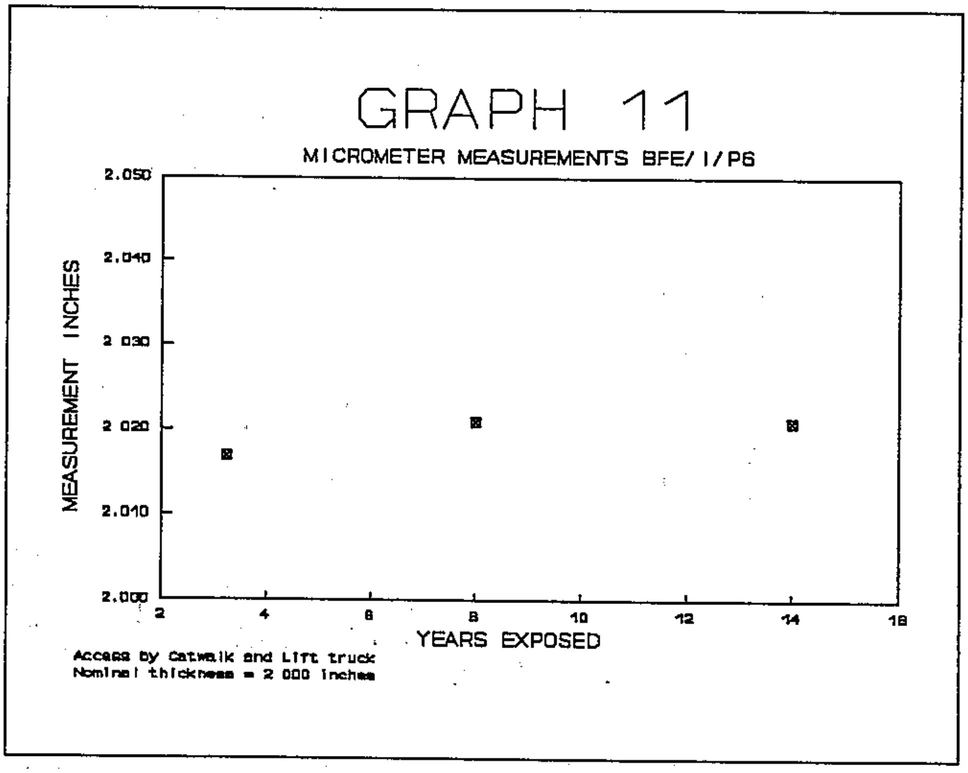

GRAPH 6
MICROMETER MEASUREMENTS BFW/O/S2
MEASUREMENT INCHES
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 1.500 inches

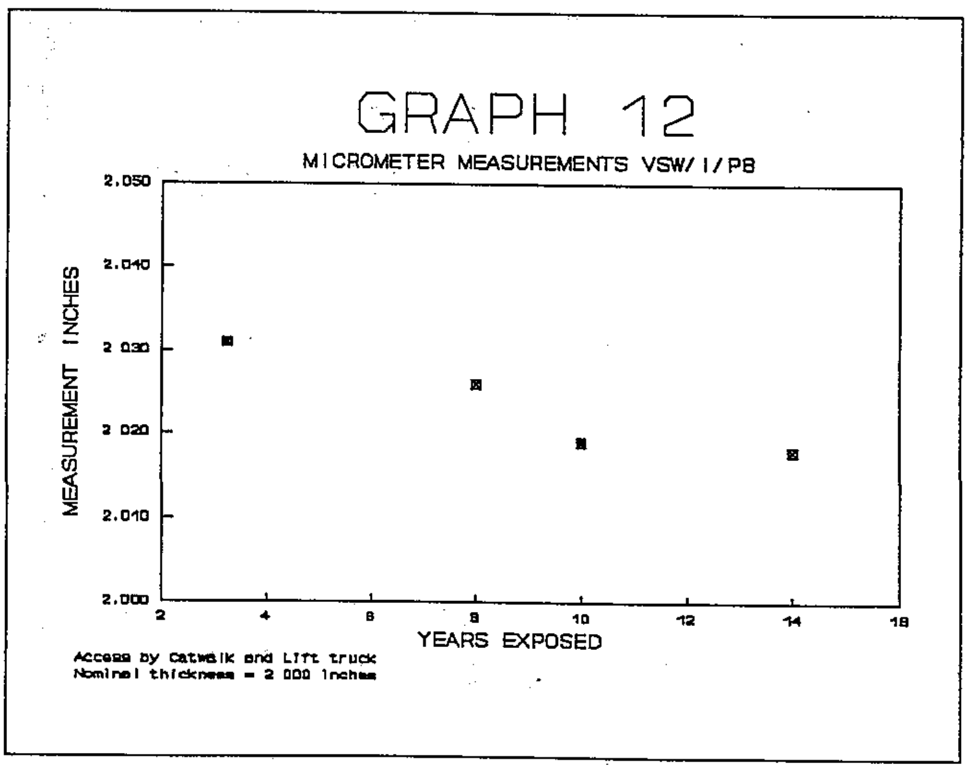

GRAPH 7
MICROMETER MEASUREMENTS BFE/O/S2
2.050
2.040
2.030
2.020
2.010
2.000
MEASUREMENT INCHES
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 Inches

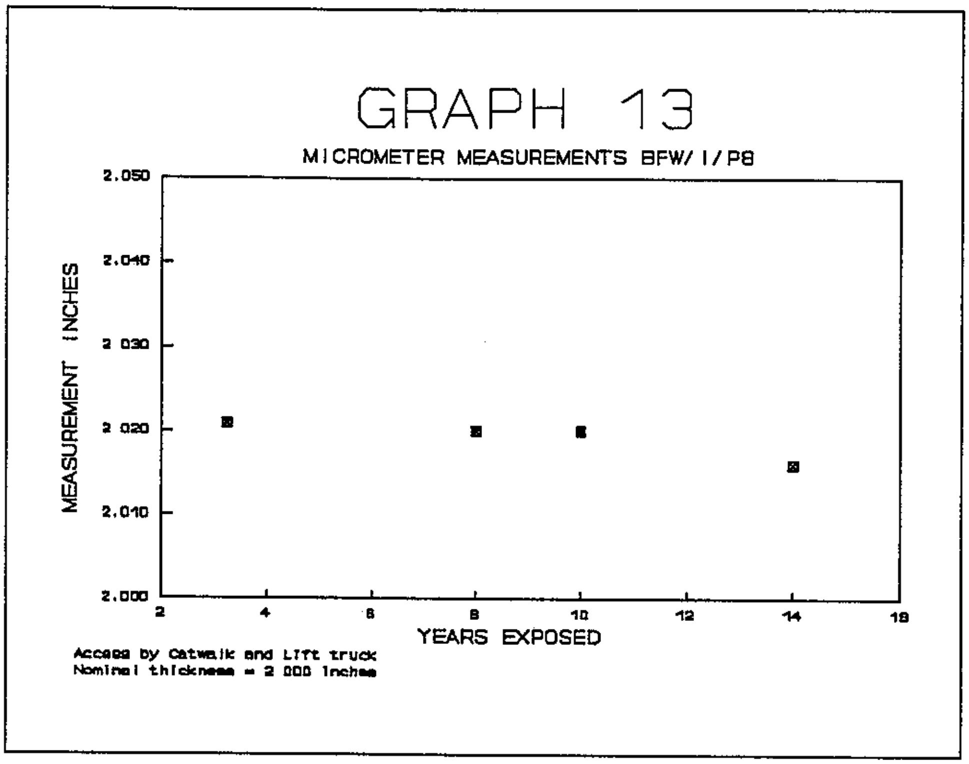

GRAPH 8
MICROMETER MEASUREMENTS VS/I/S2
0.770
0.765
0.760
0.755
0.750
MEASUREMENT INCHES
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.750 Inches

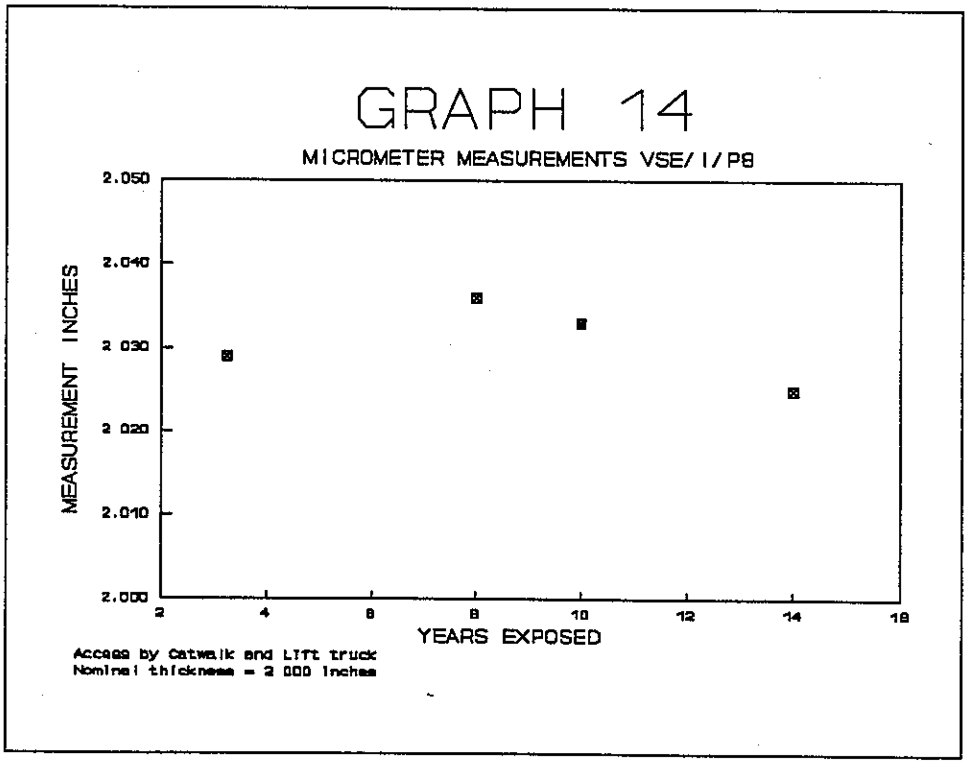

GRAPH 9
MICROMETER MEASUREMENTS VS/ I/P6
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

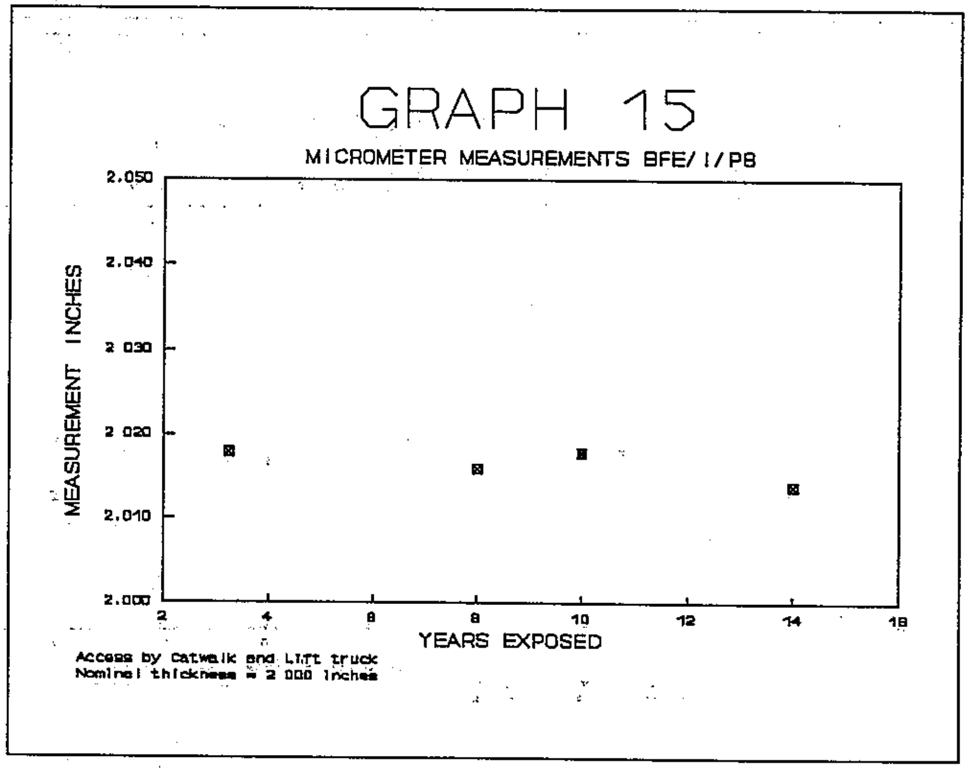

GRAPH 10
MICROMETER MEASUREMENTS BFW/ I/P6
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

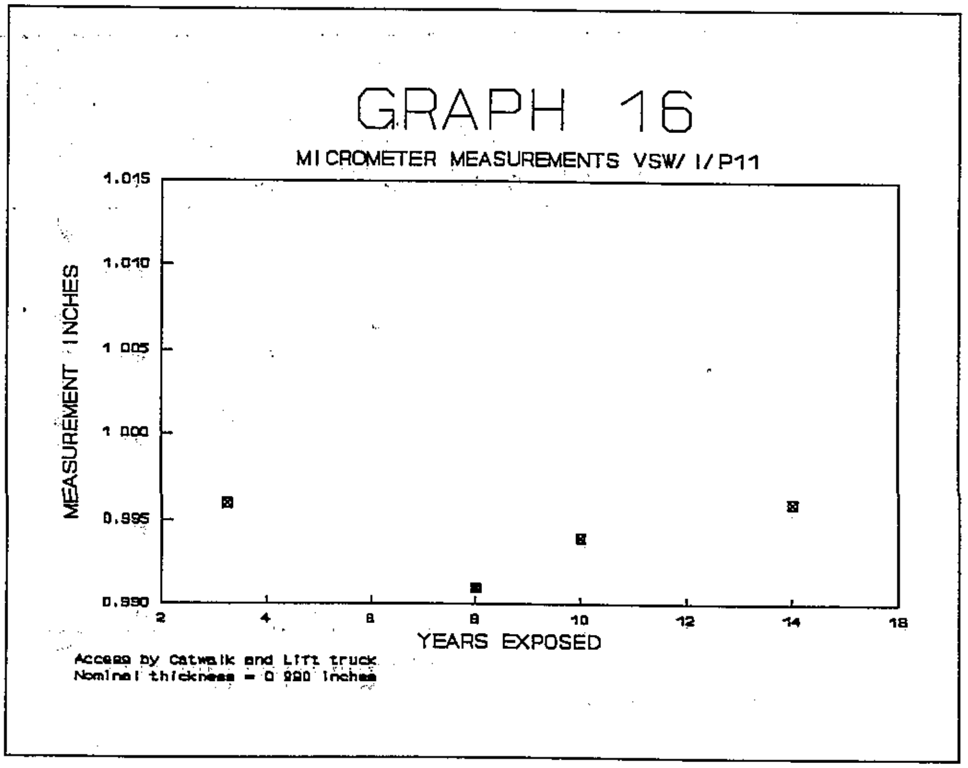

GRAPH 11
MICROMETER MEASUREMENTS BFE/ I/P6
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

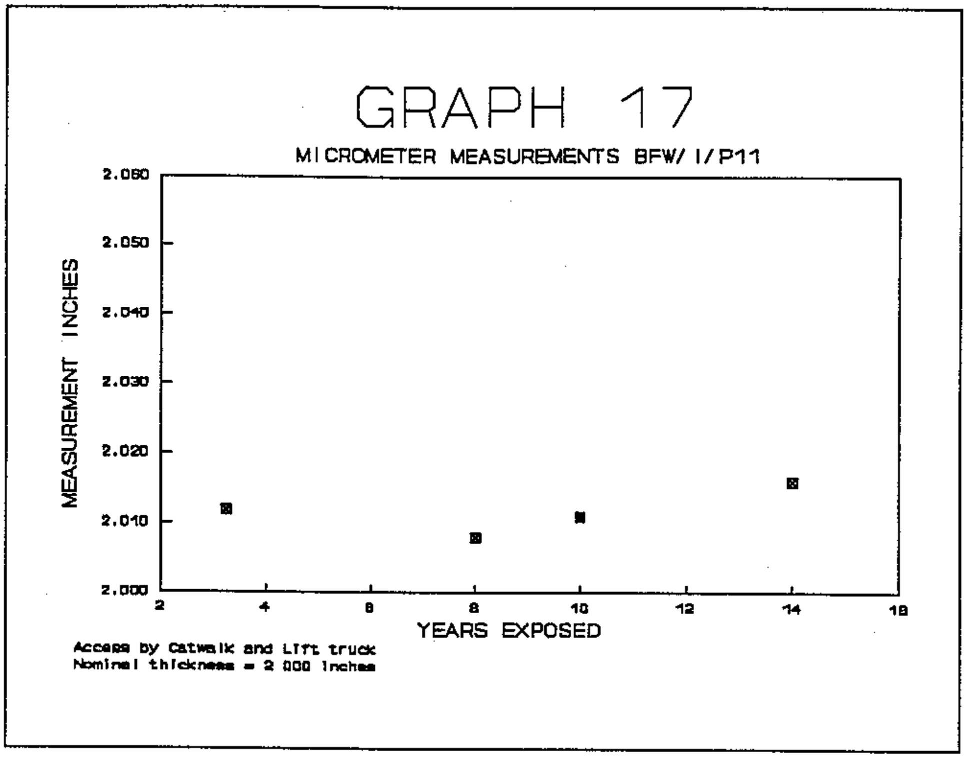

GRAPH 12
MICROMETER MEASUREMENTS VSW/ I/P8
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

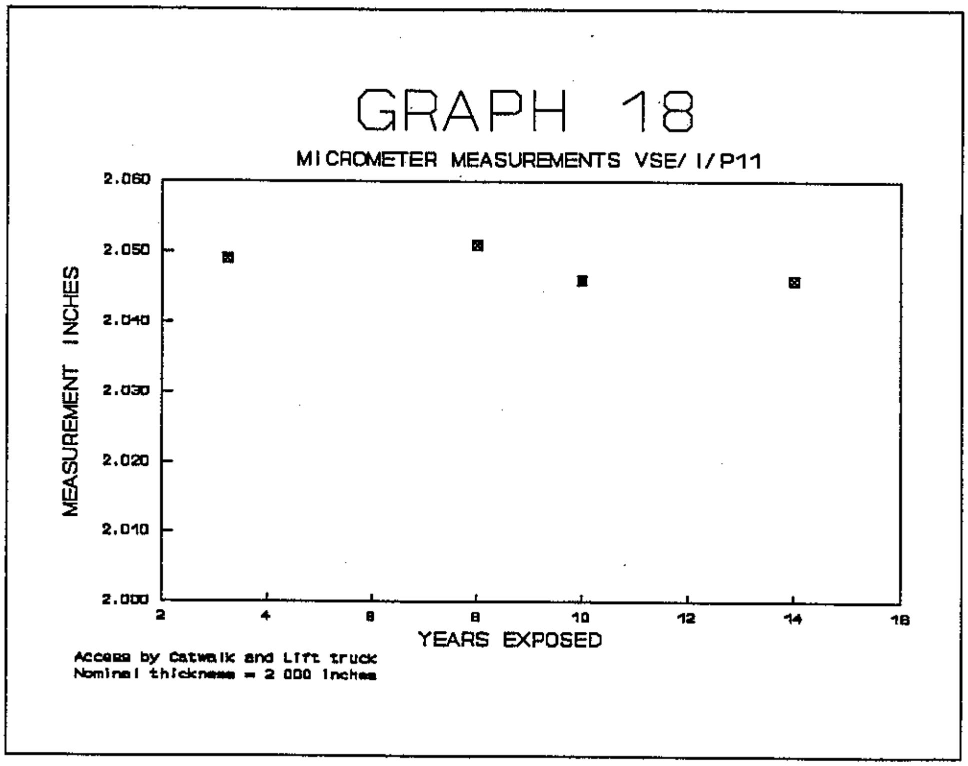

GRAPH 13
MICROMETER MEASUREMENTS BFW/ I/ P8
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

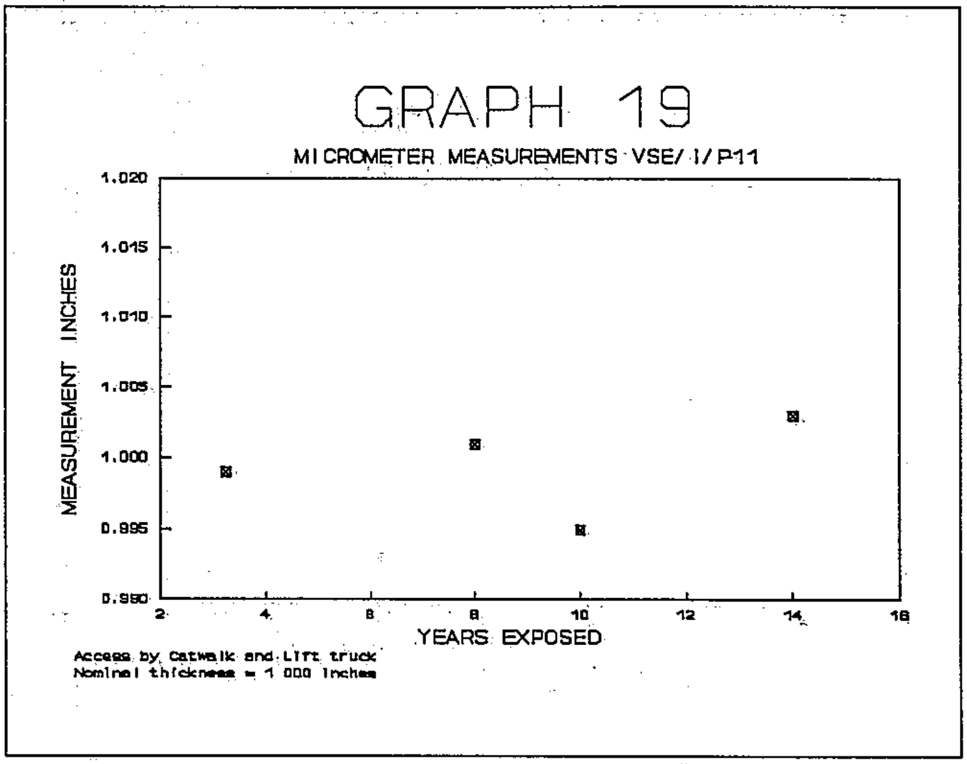

GRAPH 14
MICROMETER MEASUREMENTS VSE/ I/ P8
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

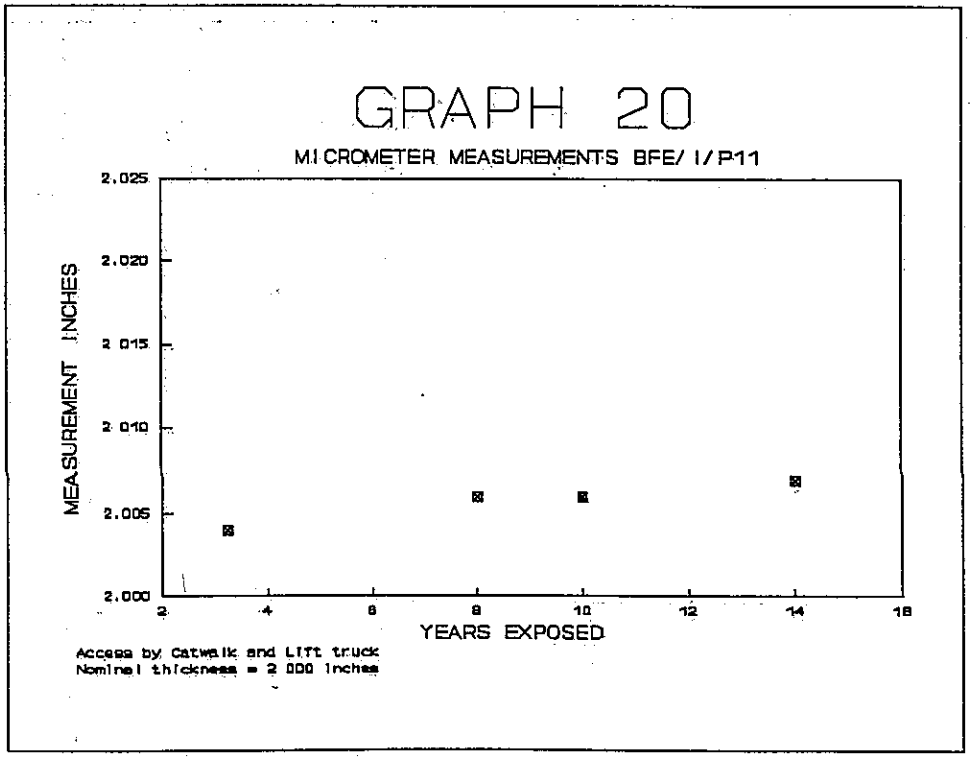

GRAPH 15
MICROMETER MEASUREMENTS BFE/I/P8
MEASUREMENT INCHES
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

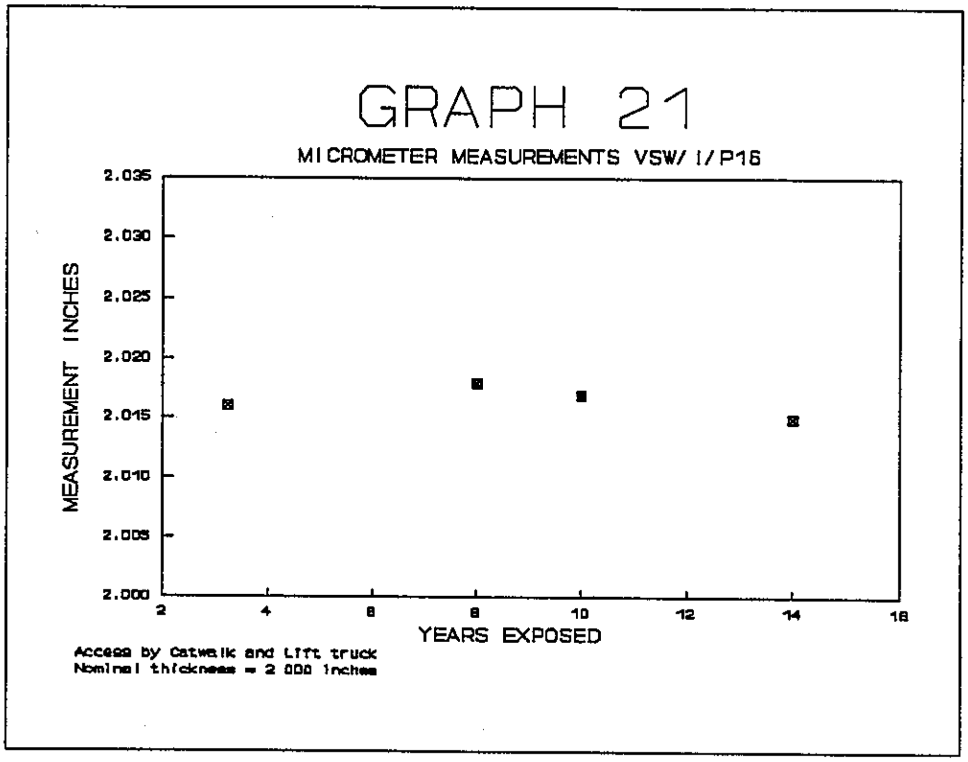

GRAPH 16
MICROMETER MEASUREMENTS VSW/I/P11
MEASUREMENT INCHES
1.015
1.010
1.005
1.000
0.995
0.990
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.990 inches

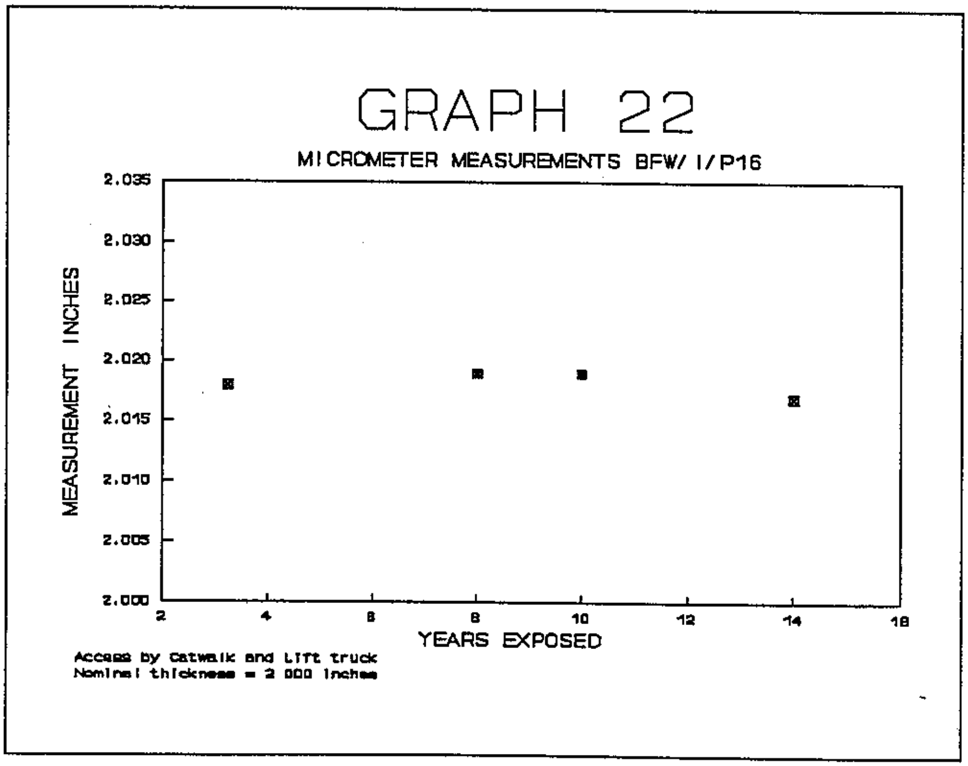

GRAPH 17
MICROMETER MEASUREMENTS BFW/ I/P11
MEASUREMENT INCHES
2.060
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

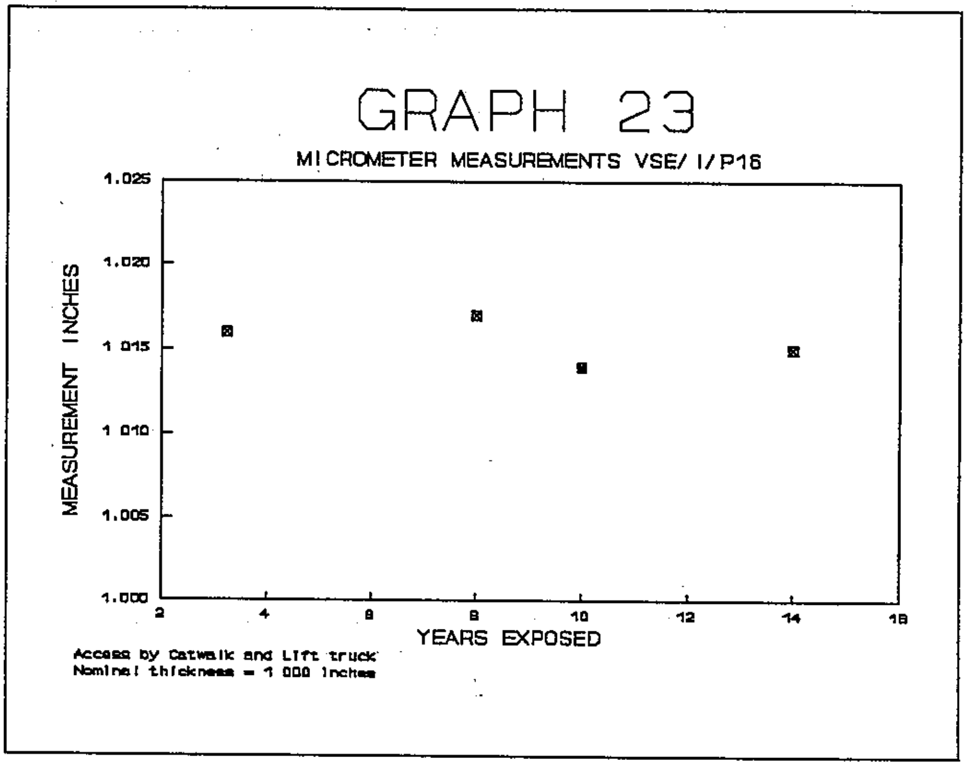

GRAPH 18
MICROMETER MEASUREMENTS VSE/ I/P11
MEASUREMENT INCHES
2.060
2.050
2.040
2.030
2.020
2.010
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

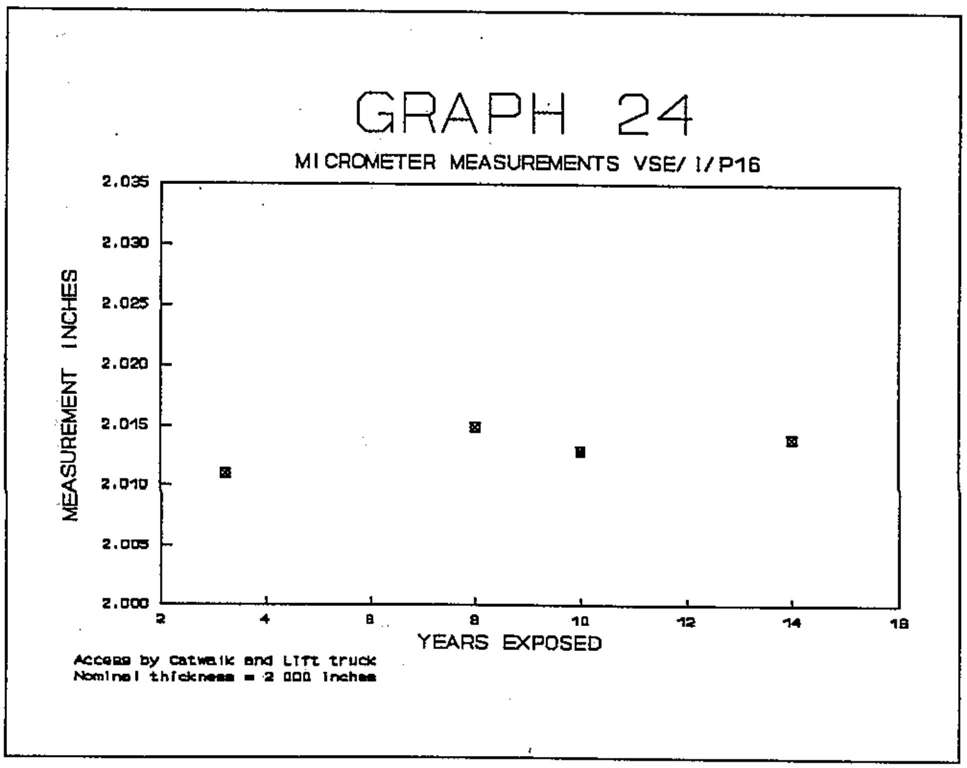

GRAPH 19
MICROMETER MEASUREMENTS VSE/ I/ P11
MEASUREMENT INCHES
1.020
1.015
1.010
1.005
1.000
0.995
0.990
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 1 000 Inches

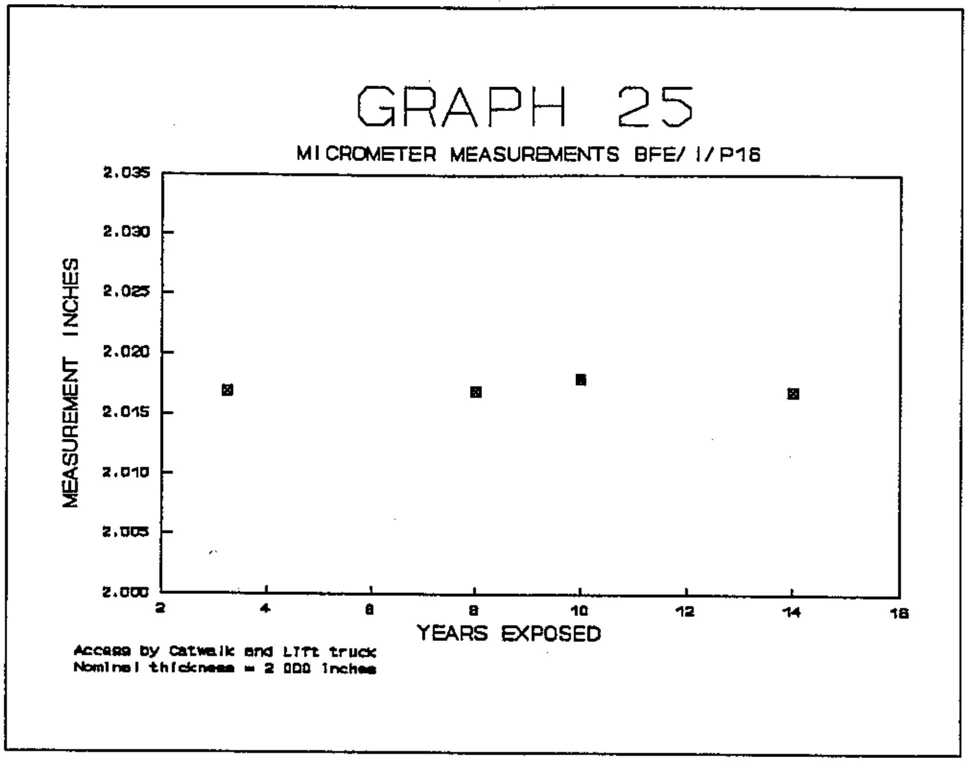

GRAPH 20
MICROMETER MEASUREMENTS BFE/ I/ P11
MEASUREMENT INCHES
2.025
2.020
2.015
2.010
2.005
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2 000 Inches

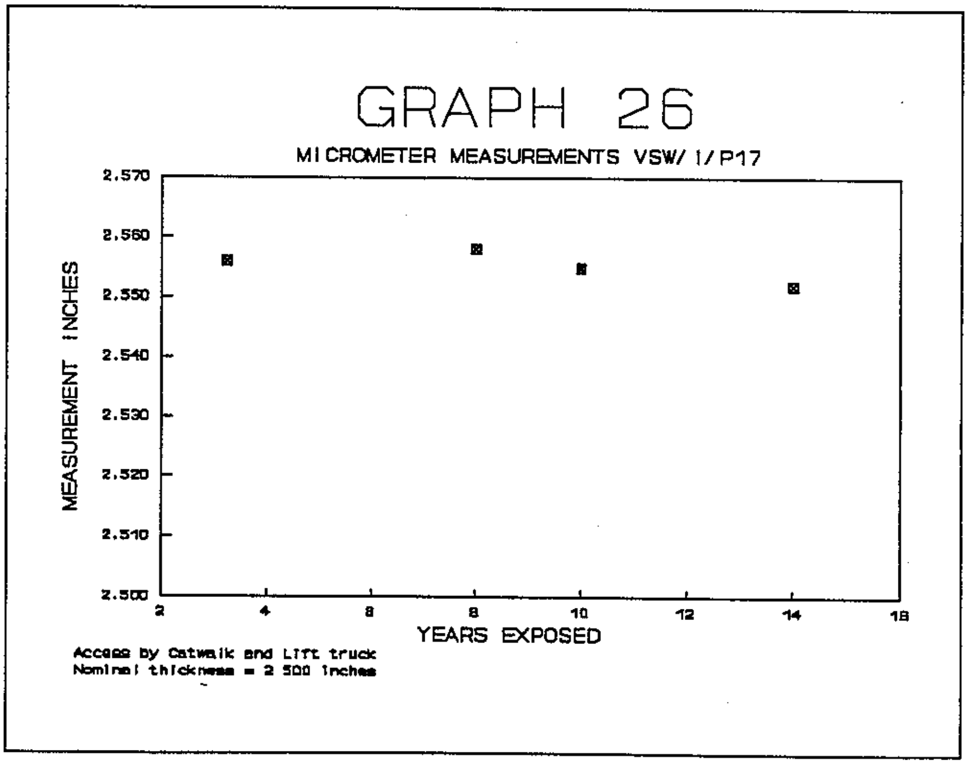

GRAPH 21
MICROMETER MEASUREMENTS VSW/ I/P16
MEASUREMENT INCHES
2.035
2.030
2.025
2.020
2.015
2.010
2.005
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

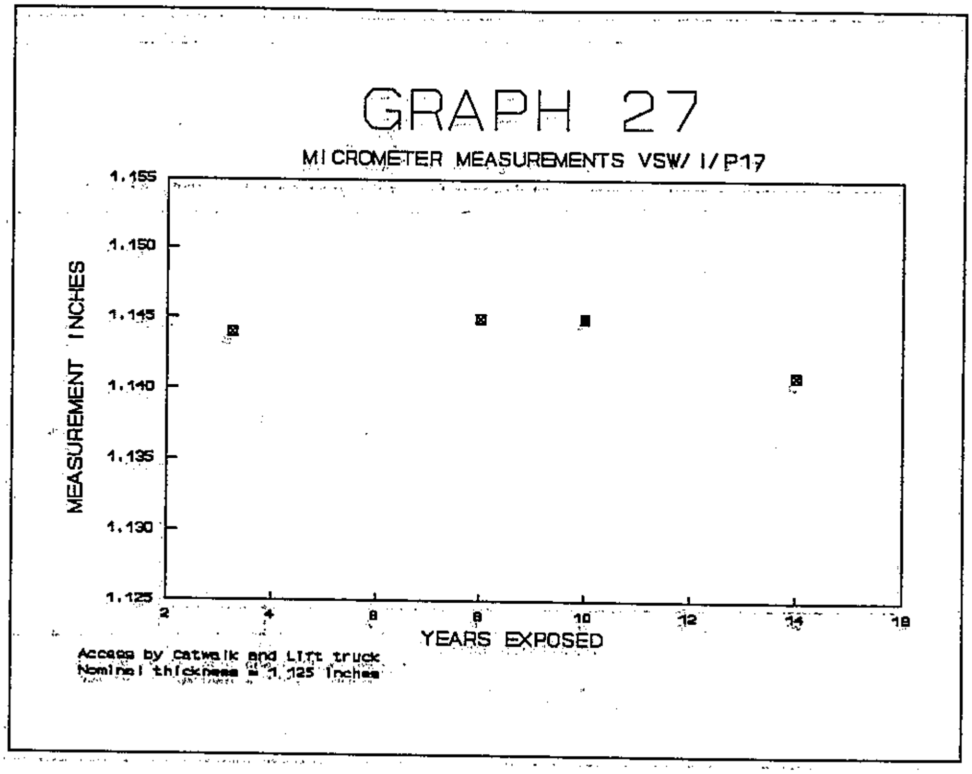

GRAPH 22
MICROMETER MEASUREMENTS BFW/ I/P16
MEASUREMENT INCHES
2.035
2.030
2.025
2.020
2.015
2.010
2.005
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

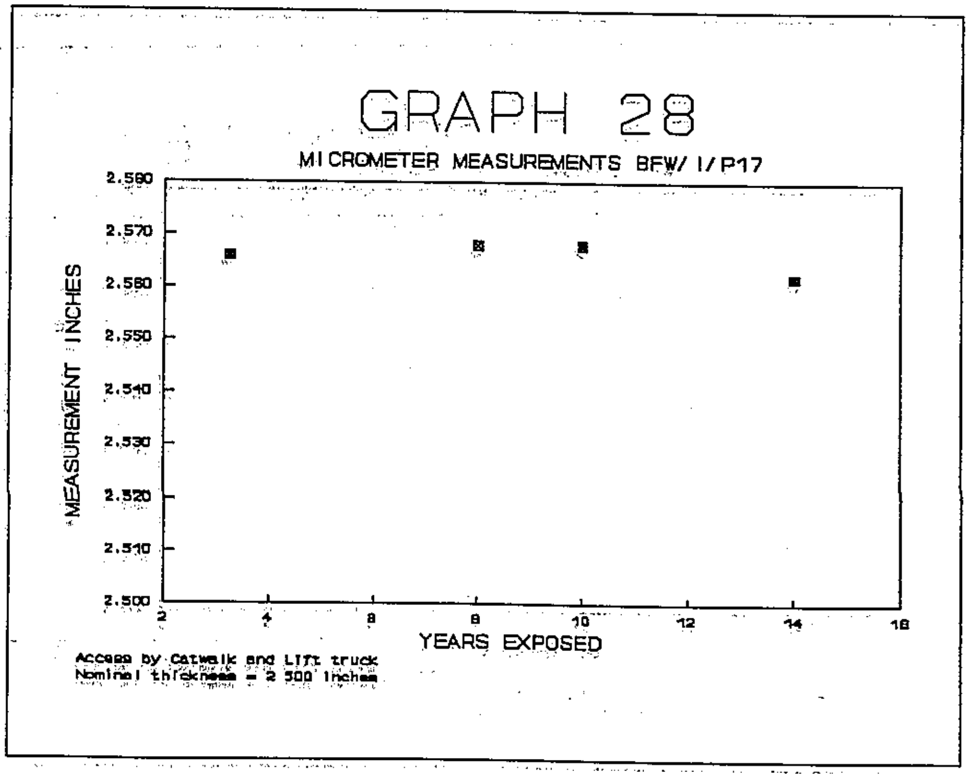

GRAPH 23
MICROMETER MEASUREMENTS VSE/I/P16
MEASUREMENT INCHES
1.025
1.020
1.015
1.010
1.005
1.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 1.000 inches

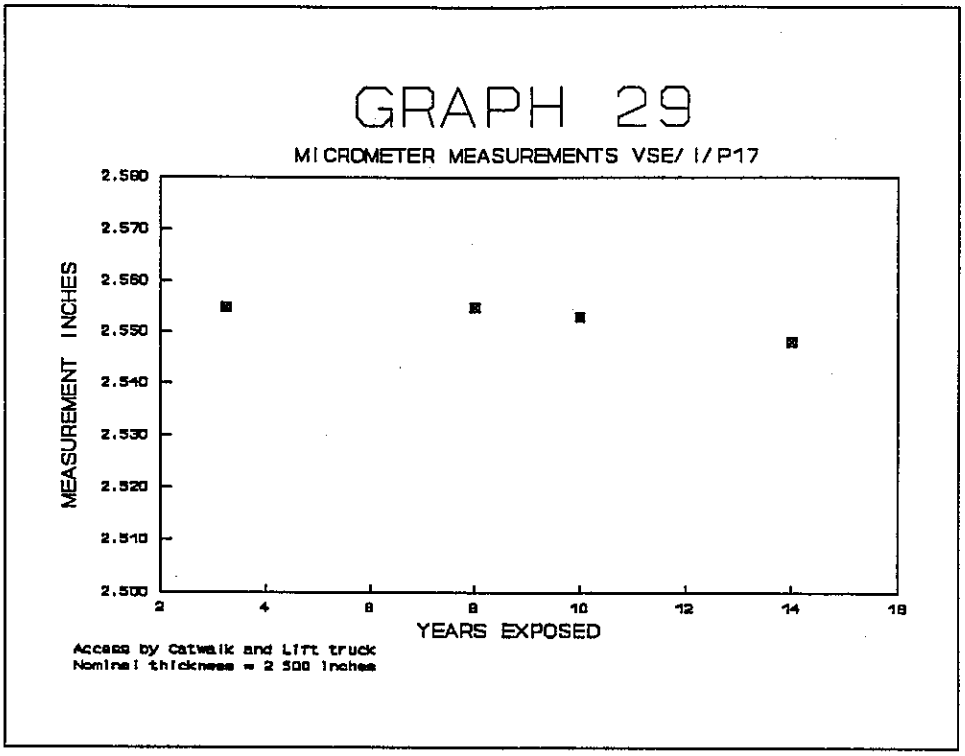

GRAPH 24
MICROMETER MEASUREMENTS VSE/I/P16
MEASUREMENT INCHES
2.035
2.030
2.025
2.020
2.015
2.010
2.005
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.000 inches

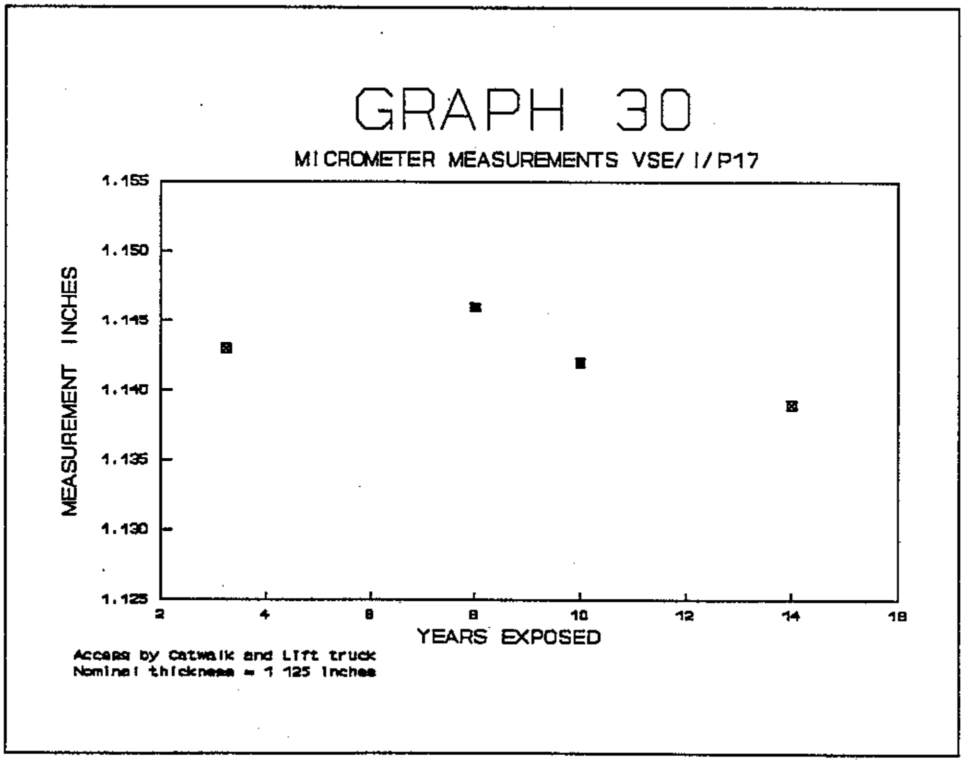

GRAPH 25
MICROMETER MEASUREMENTS BFE/ I/P16
MEASUREMENT INCHES
2.035
2.030
2.025
2.020
2.015
2.010
2.005
2.000
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2 000 inches

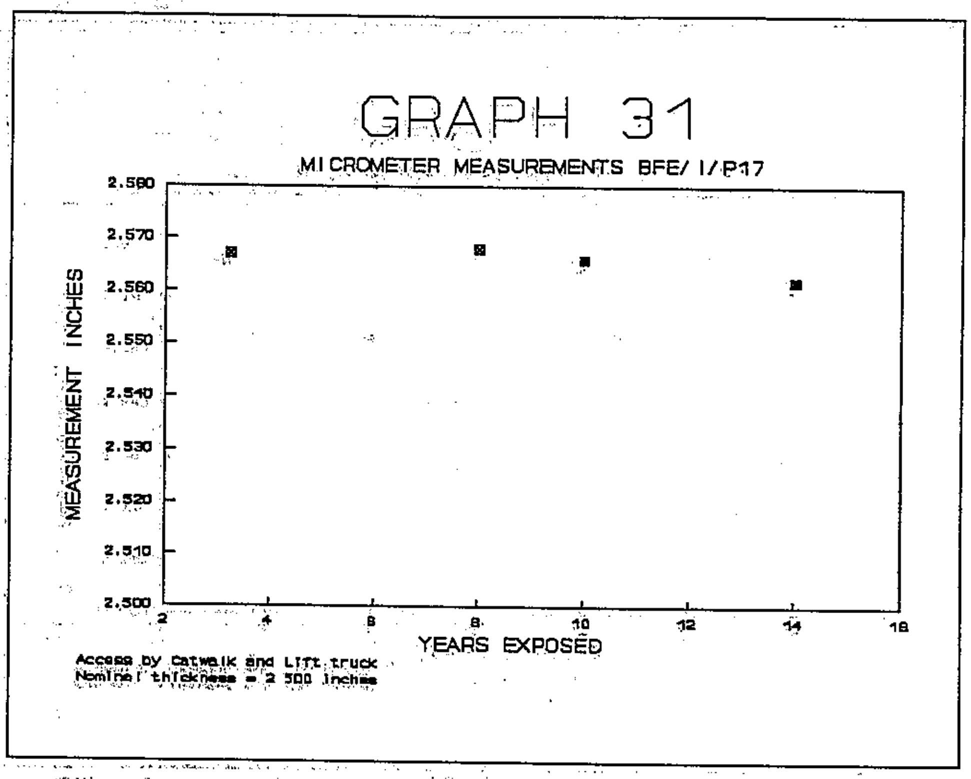

GRAPH 26
MICROMETER MEASUREMENTS VSW/ I/P17
MEASUREMENT INCHES
2.570
2.560
2.550
2.540
2.530
2.520
2.510
2.500
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2 500 inches

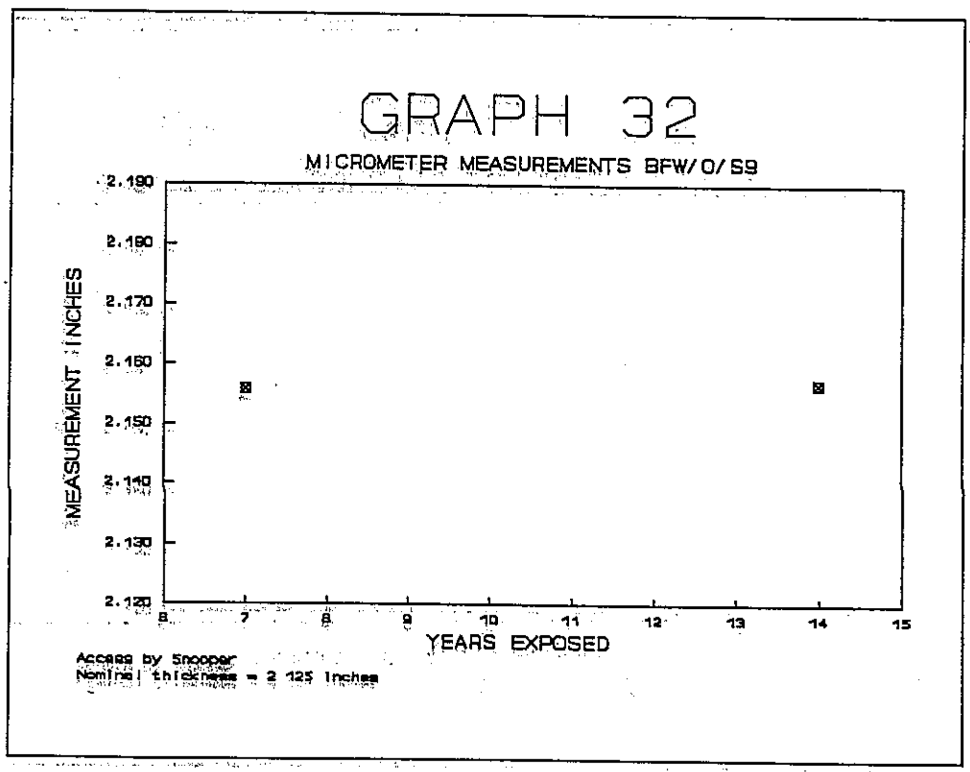

GRAPH 27
MICROMETER MEASUREMENTS VSW/ I/ P17
MEASUREMENT INCHES
1.155
1.150
1.145
1.140
1.135
1.130
1.125
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 1.125 inches

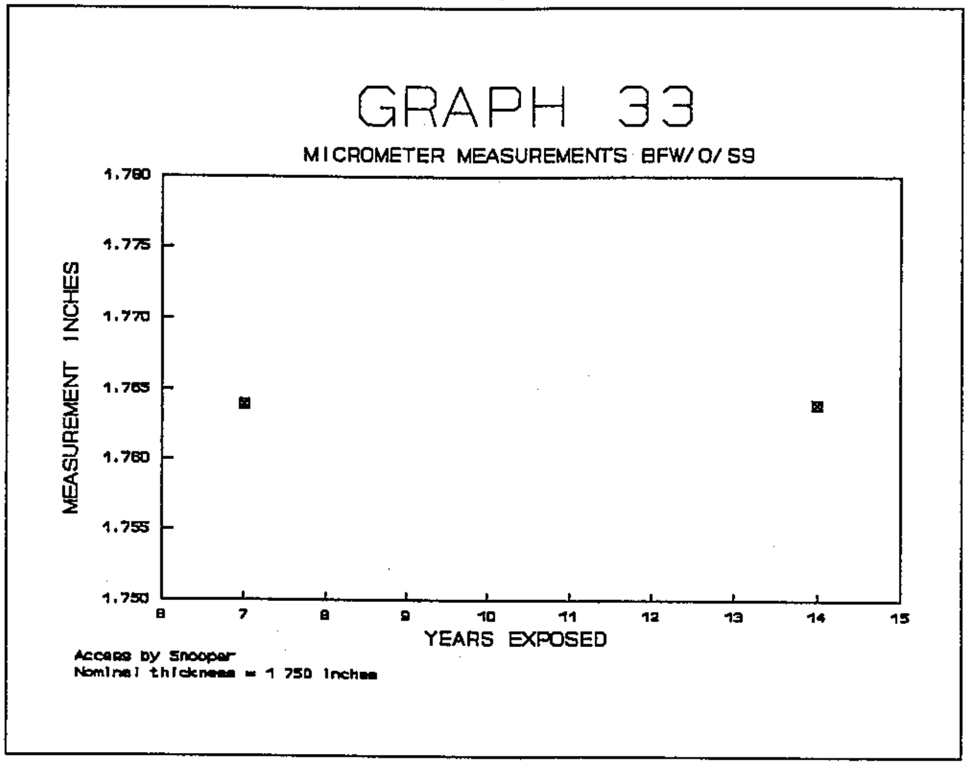

GRAPH 28
MICROMETER MEASUREMENTS BFW/ I/ P17
MEASUREMENT INCHES
2.580
2.570
2.560
2.550
2.540
2.530
2.520
2.510
2.500
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.500 inches

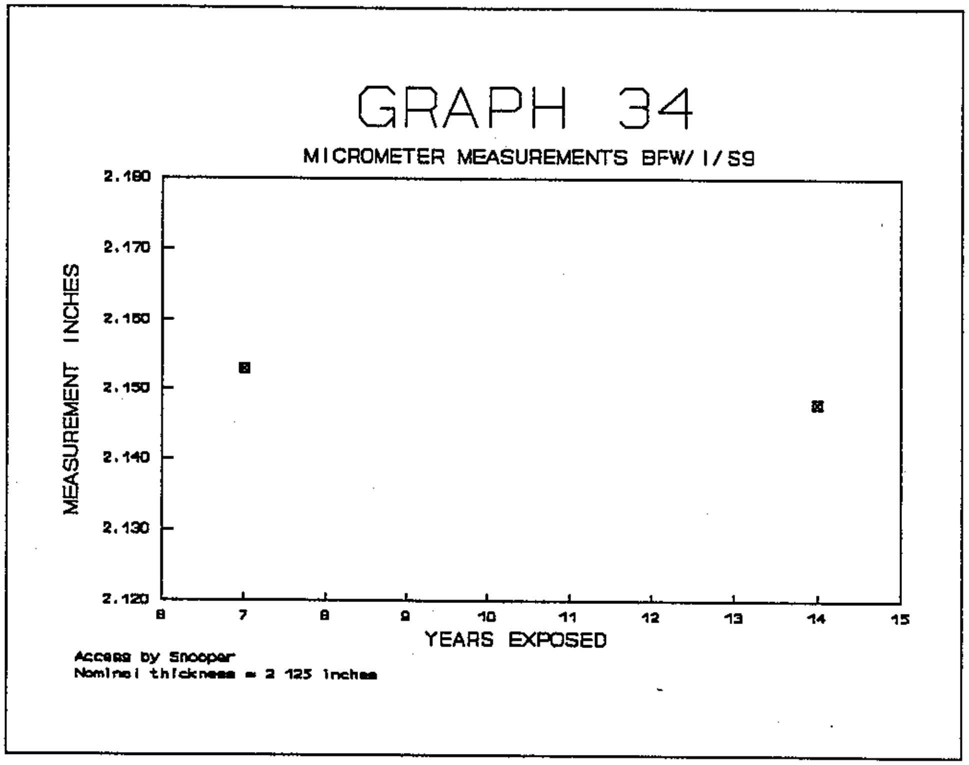

GRAPH 29
MICROMETER MEASUREMENTS VSE/ I/P17
MEASUREMENT INCHES
2.580
2.570
2.560
2.550
2.540
2.530
2.520
2.510
2.500
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2 500 inches

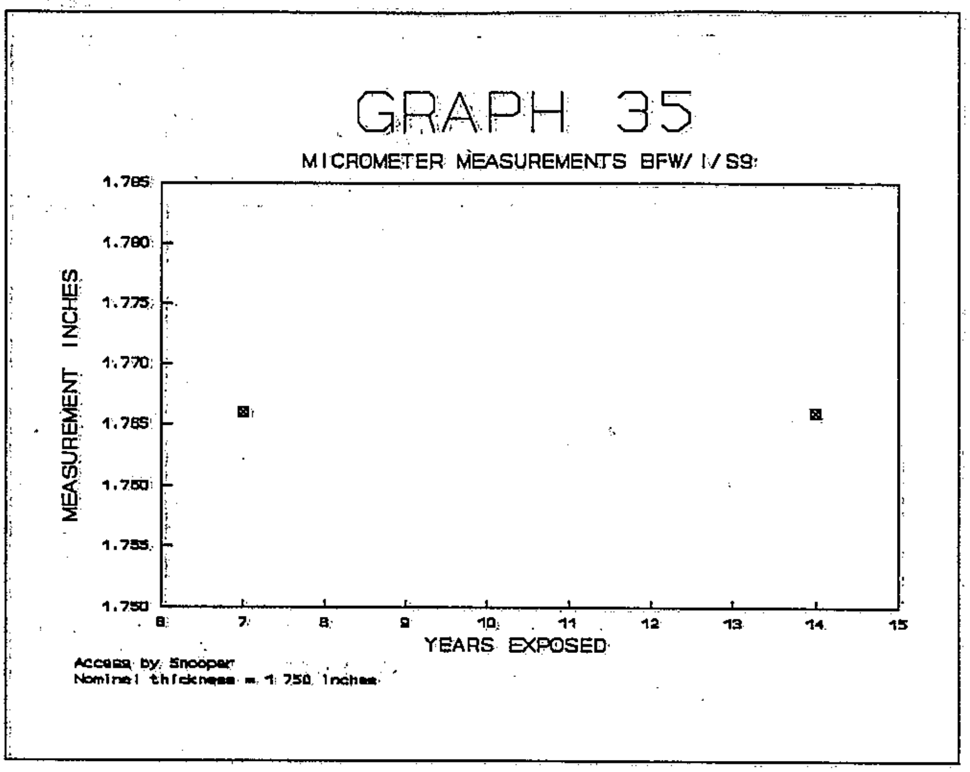

GRAPH 30
MICROMETER MEASUREMENTS VSE/ I/P17
MEASUREMENT INCHES
1.155
1.150
1.145
1.140
1.135
1.130
1.125
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 1 125 inches

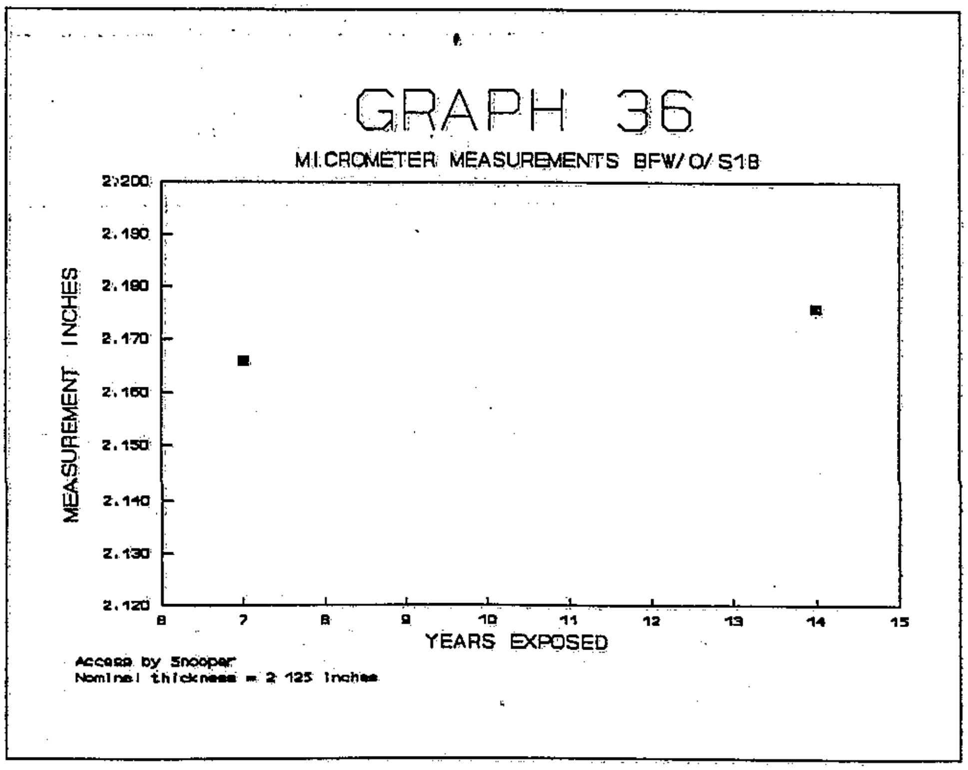

GRAPH 31
MICROMETER MEASUREMENTS BFE/ I/ P17
MEASUREMENT INCHES
2.580
2.570
2.560
2.550
2.540
2.530
2.520
2.510
2.500
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 2.500 inches


GRAPH 32
MICROMETER MEASUREMENTS BFW/ O/ S9
MEASUREMENT INCHES
2.190
2.180
2.170
2.160
2.150
2.140
2.130
2.120
6
7
8
9
10
11
12
13
14
15
YEARS EXPOSED
Access by Snooper
Nominal thickness = 2.125 inches


GRAPH 33
MICROMETER MEASUREMENTS BFW/0/S9
MEASUREMENT INCHES
1.780
1.775
1.770
1.765
1.760
1.755
1.750
6
7
8
9
10
11
12
13
14
15
YEARS EXPOSED
Access by Snooper
Nominal thickness = 1 750 inches

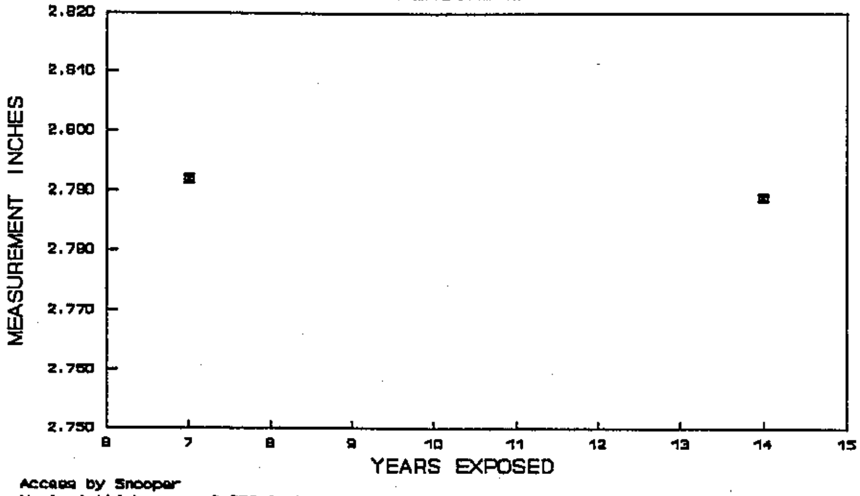

GRAPH 34
MICROMETER MEASUREMENTS BFW/1/S9
MEASUREMENT INCHES
2.180
2.170
2.160
2.150
2.140
2.130
2.120
6
7
8
9
10
11
12
13
14
15
YEARS EXPOSED
Access by Snooper
Nominal thickness = 2 125 inches


GRAPH 35
MICROMETER MEASUREMENTS BFW/ I/ S9
MEASUREMENT INCHES
YEARS EXPOSED
Access by Snooper
Nominal thickness = 1.750 inches


GRAPH 36
MICROMETER MEASUREMENTS BFW/ O/ S18
MEASUREMENT INCHES
YEARS EXPOSED
Access by Snooper
Nominal thickness = 2.125 inches

GRAPH 37

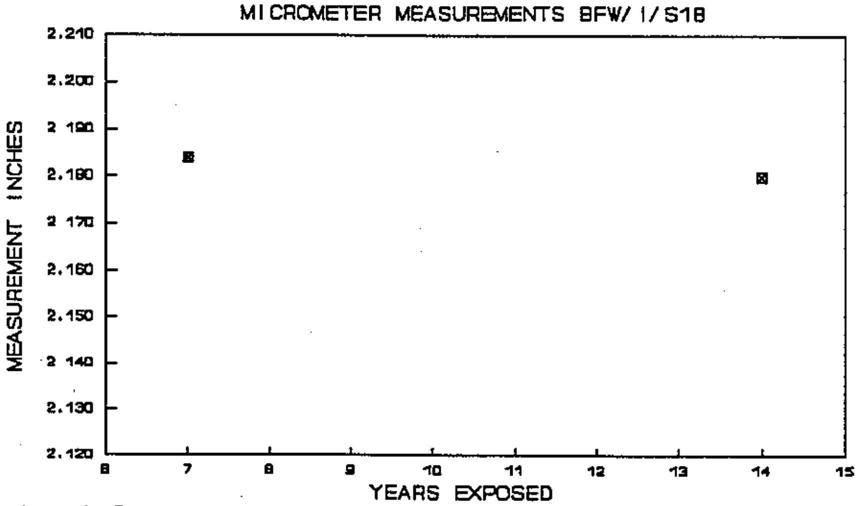
MICROMETER MEASUREMENTS BFW/O/S18



Access by Snooper
Nominal thickness = 2 750 inches

GRAPH 38

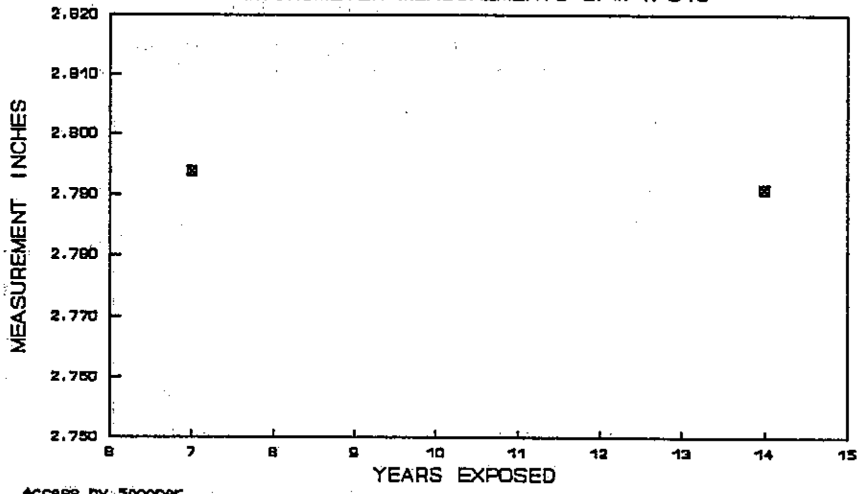
MICROMETER MEASUREMENTS BFW/1/S18



Access by Snooper
Nominal thickness = 2 125 inches

GRAPH 39

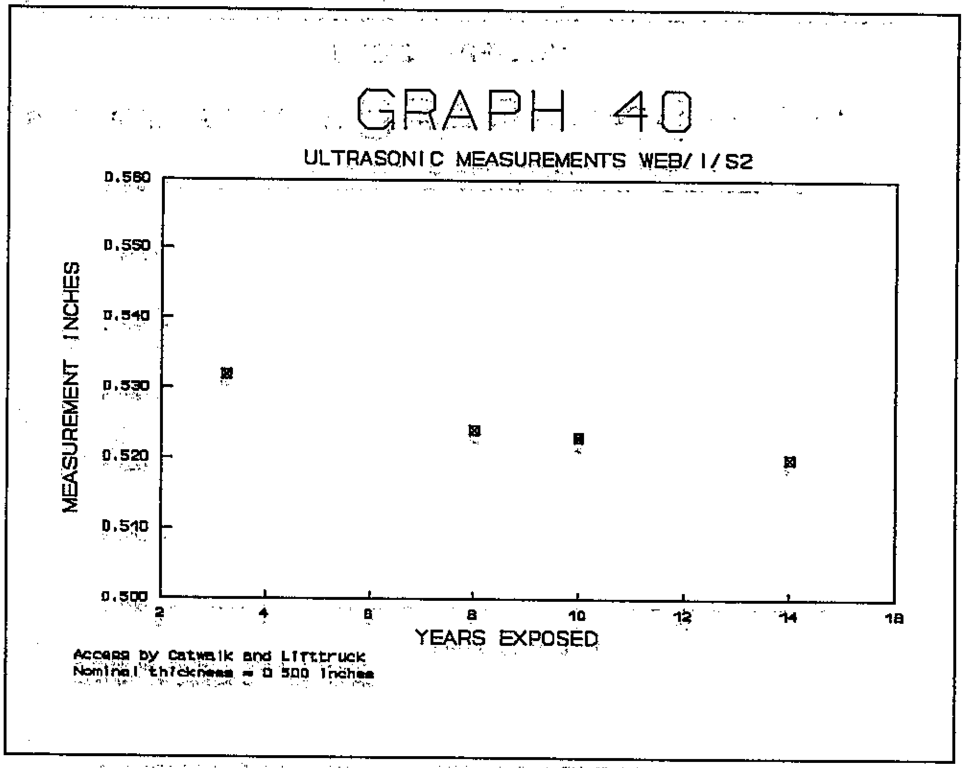
MICROMETER MEASUREMENTS BFW/ 1/S18

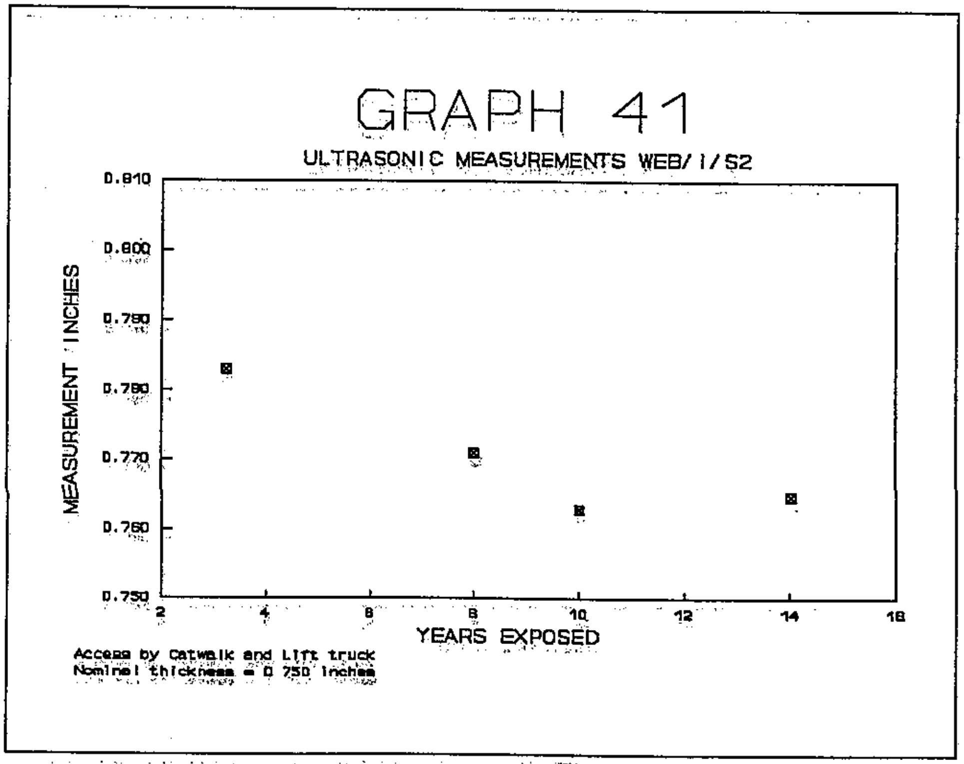


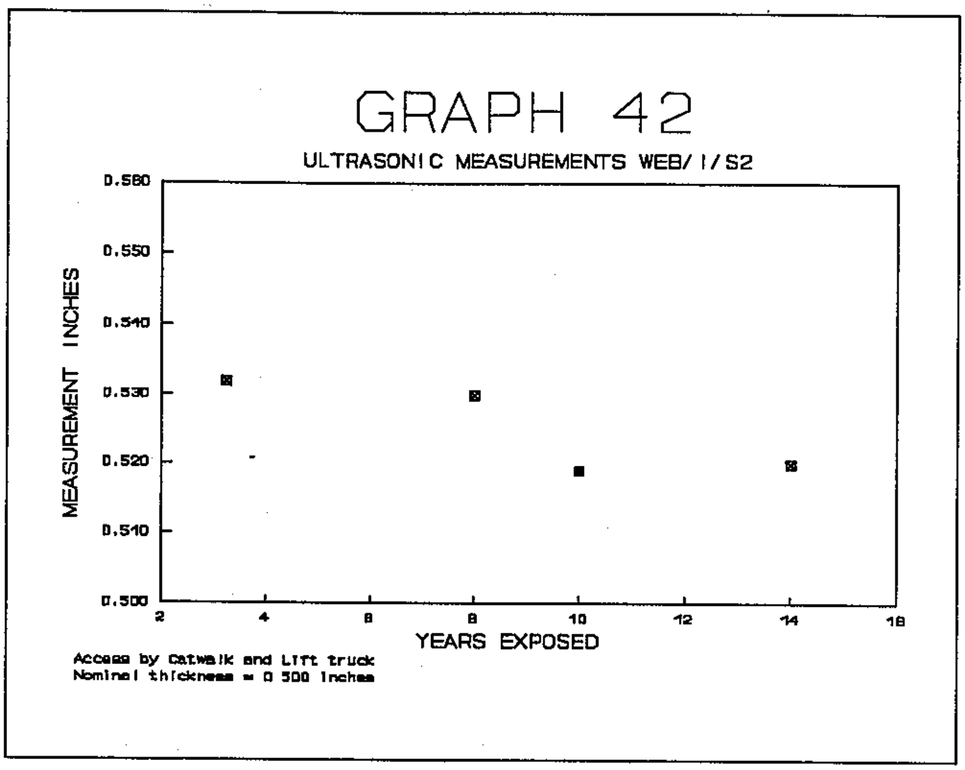
Access by Snooper
Nominal thickness = 2.750 inches

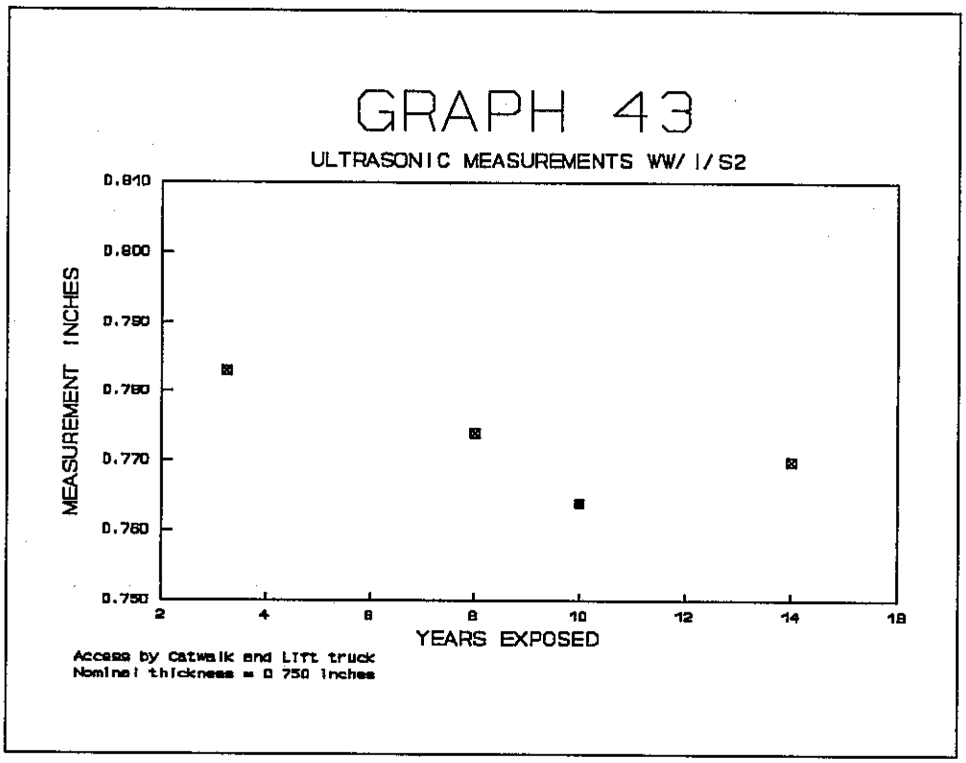
18. APPENDIX B

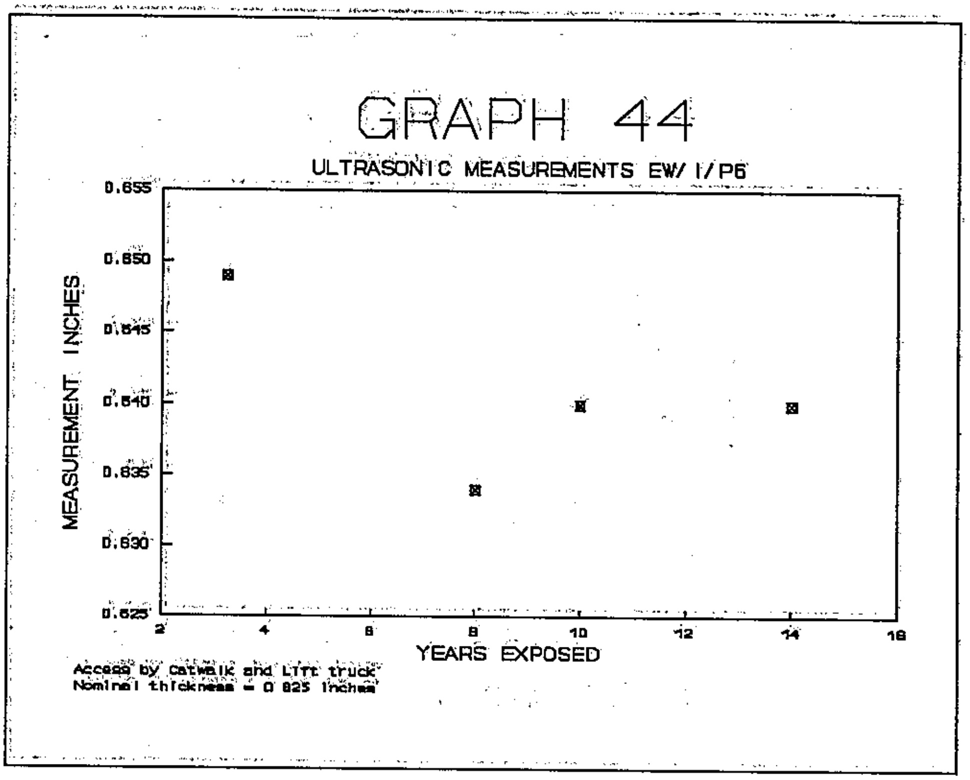
GRAPHS OF ULTRASONIC THICKNESS MEASUREMENTS

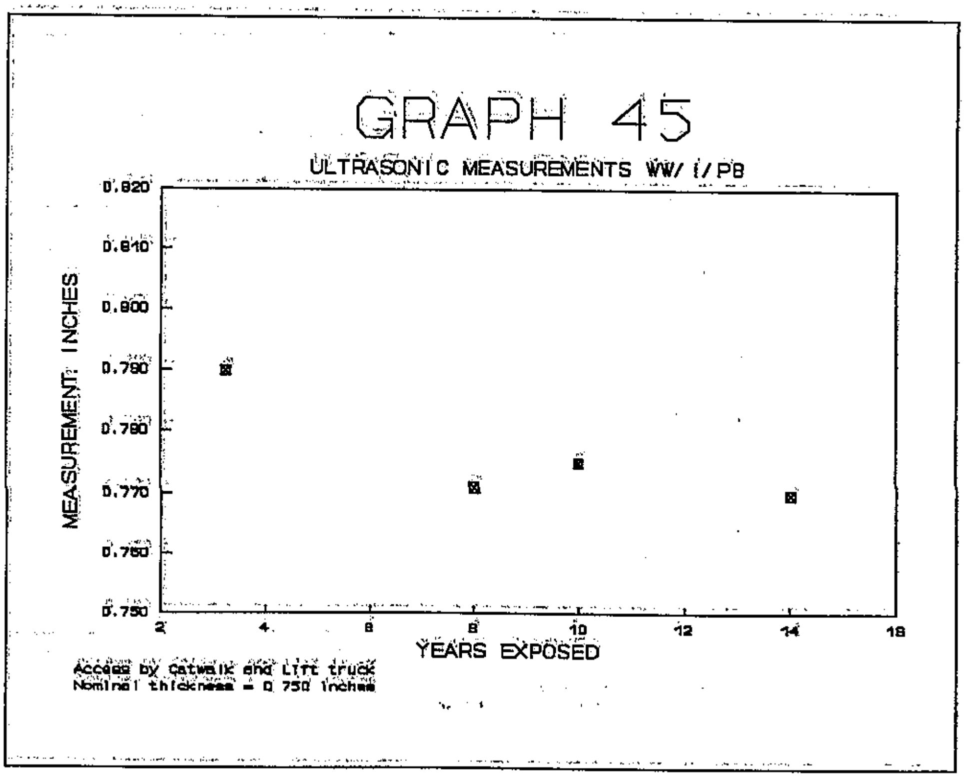

GRAPH 40
ULTRASONIC MEASUREMENTS WEB/ I / S2
MEASUREMENT INCHES
0.560
0.550
0.540
0.530
0.520
0.510
0.500
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lifttruck
Nominal thickness = 0.500 inches

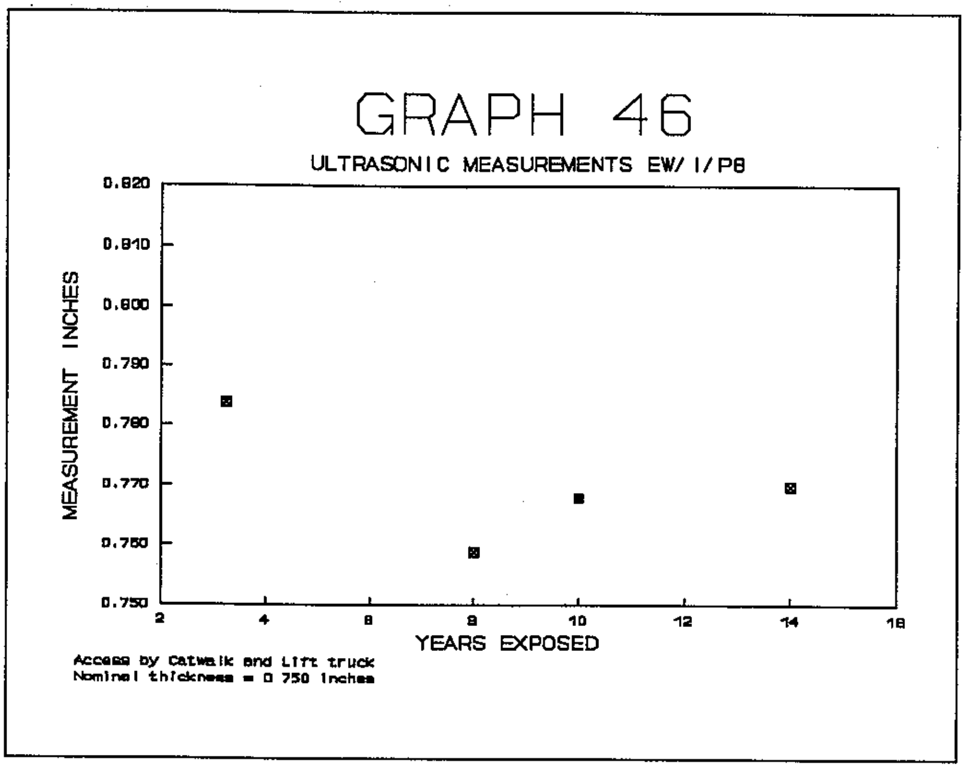

GRAPH 41
ULTRASONIC MEASUREMENTS WEB/ I / S2
MEASUREMENT INCHES
0.810
0.800
0.790
0.780
0.770
0.760
0.750
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.750 inches

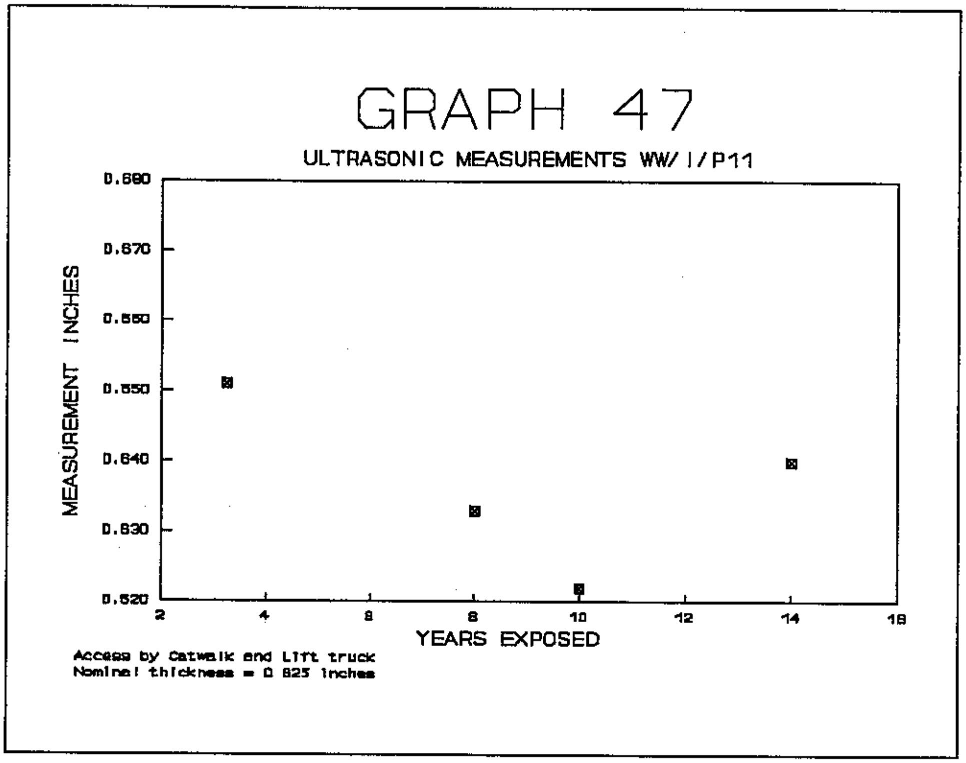

GRAPH 42
ULTRASONIC MEASUREMENTS WEB/ I / S2
MEASUREMENT INCHES
0.560
0.550
0.540
0.530
0.520
0.510
0.500
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.500 Inches

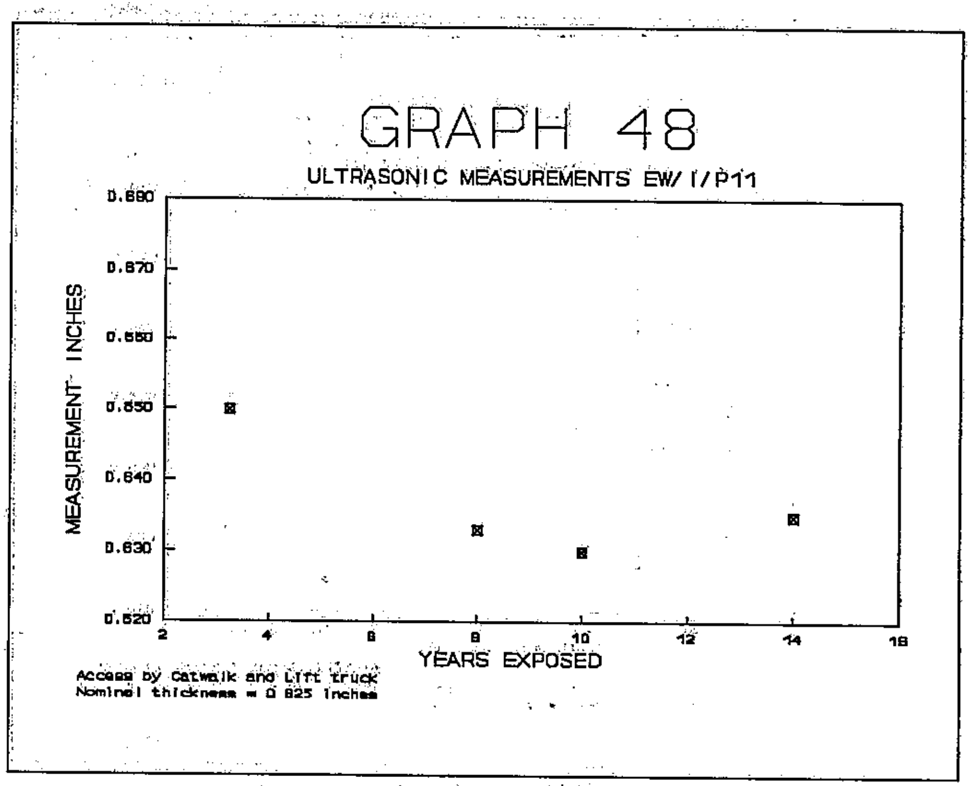

GRAPH 43
ULTRASONIC MEASUREMENTS WW/ I / S2
MEASUREMENT INCHES
0.810
0.800
0.790
0.780
0.770
0.760
0.750
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.750 Inches

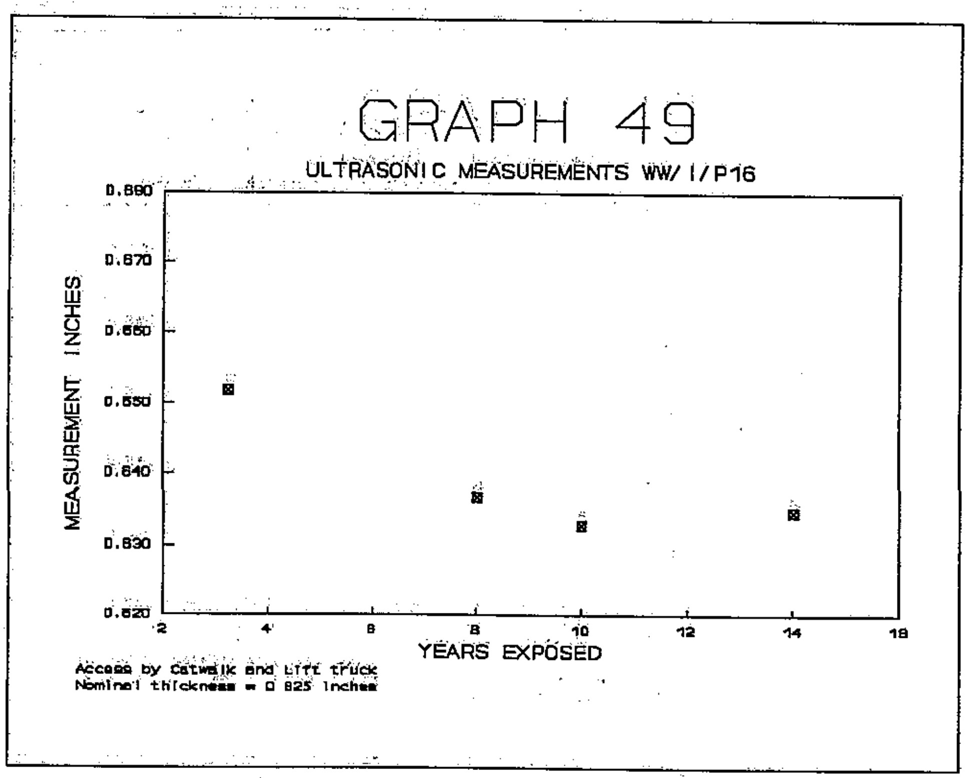

GRAPH 44
ULTRASONIC MEASUREMENTS EW/ I/P6
MEASUREMENT INCHES
0.655
0.650
0.645
0.640
0.635
0.630
0.625
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.625 inches

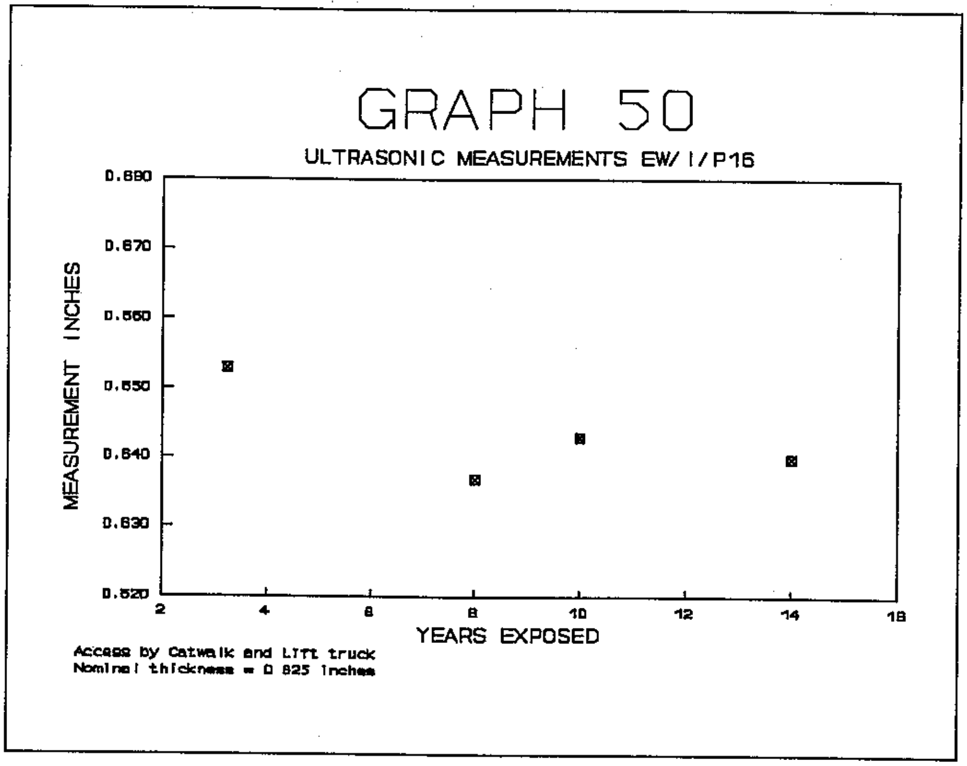

GRAPH 45
ULTRASONIC MEASUREMENTS WW/ I/P8
MEASUREMENT INCHES
0.820
0.810
0.800
0.790
0.780
0.770
0.760
0.750
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.750 inches

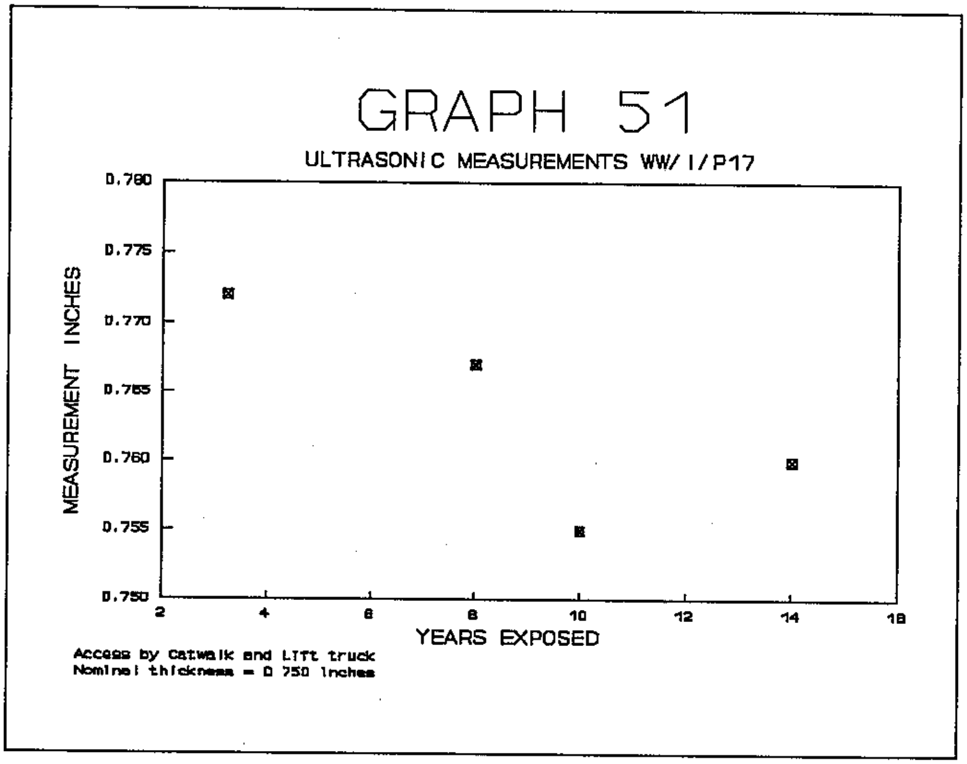

GRAPH 46
ULTRASONIC MEASUREMENTS EW/ I/P8
MEASUREMENT INCHES
0.820
0.810
0.800
0.790
0.780
0.770
0.760
0.750
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0 750 inches


GRAPH 47
ULTRASONIC MEASUREMENTS WW/ I/P11
MEASUREMENT INCHES
0.680
0.670
0.660
0.650
0.640
0.630
0.620
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0 625 inches


GRAPH 48
ULTRASONIC MEASUREMENTS EW/ I/P11
MEASUREMENT INCHES
0.680
0.670
0.660
0.650
0.640
0.630
0.620
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.625 inches


GRAPH 49
ULTRASONIC MEASUREMENTS WW/ I/P16
MEASUREMENT INCHES
0.680
0.670
0.660
0.650
0.640
0.630
0.620
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.625 inches


GRAPH 50
ULTRASONIC MEASUREMENTS EW/ I / P16
MEASUREMENT INCHES
0.680
0.670
0.660
0.650
0.640
0.630
0.620
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.625 inches


GRAPH 51
ULTRASONIC MEASUREMENTS WW/ I / P17
MEASUREMENT INCHES
0.780
0.775
0.770
0.765
0.760
0.755
0.750
2
4
6
8
10
12
14
16
YEARS EXPOSED
Access by Catwalk and Lift truck
Nominal thickness = 0.750 inches

19. APPENDIX C

TABLES OF MICROMETER AND ULTRASONIC THICKNESS MEASUREMENTS

'Micrometer Measurements Inches

Num	Location	Access	Nom Thk	Exposure Years 3.25	8.0	10.0	14.0
1	BFW/I/S2	Lift Trk	1.500	1.527	1.525	1.524	1.522
2	BFW/I/P2		2.000	2.034	2.030	2.033	2.032
6	BFW/O/S1	"	1.750	1.786	1.786	1.785	1.782
7	BFW/O/S1	"	2.000	2.030	2.030	2.034	2.035
8	LS/O/S1	"	0.750	0.771	0.768	0.775	No Mea
9	BFW/O/S2	"	1.500	1.532	1.532	No Mea	1.532
10	BFE/O/S2	"	2.000	2.029	2.032	2.034	2.030
11	VS/I/S2	"	0.750	0.754	0.755	0.754	No Mea
16	VSW/I/P6	Cat Walk	2.000	2.024	2.024	2.022	2.021
17	BFW/I/P6	"	2.000	2.032	2.030	2.033	2.033
20	BFE/I/P6	"	2.000	2.017	2.021	No Mea	2.021
22	VSW/I/P8	"	2.000	2.031	2.026	2.019	2.018
23	BFW/I/P8	"	2.000	2.021	2.020	2.020	2.016
25	VSE/I/P8	"	2.000	2.029	2.036	2.033	2.025
26	BFE/I/P8	"	2.000	2.018	2.016	2.018	2.014
29	VSW/I/P11	"	1.000	0.996	0.991	0.994	0.996
30	BFW/I/P11	"	2.000	2.012	2.008	2.011	2.016
32	VSE/I/P11	"	2.000	2.049	2.051	2.046	2.046
33	VSE/I/P11	"	1.000	0.999	1.001	0.995	1.003
34	BFE/I/P11	"	2.000	2.004	2.006	2.006	2.007

Num	Location	Access	Nom Thk	Exposure Years 3.25	8.0	10.0	14.0
36	VSW/I/P16	Catwalk	2.000	2.016	2.018	2.017	2.015
38	BFW/I/P16		2.000	2.018	2.019	2.019	2.017
40	VSE/I/P16	"	1.000	1.016	1.017	1.014	1.015
41	VSE/I/P16	"	2.000	2.011	2.015	2.013	2.014
42	BFE/I/P16	"	2.000	2.017	2.017	2.018	2.017
44	VSW/I/P17	"	2.500	2.556	2.558	2.555	2.552
45	VSW/I/P17	"	1.125	1.144	1.145	1.145	1.141
46	BFW/I/P17	"	2.500	2.566	2.568	2.568	2.562
48	VSE/I/P17	"	2.500	2.555	2.555	2.553	2.548
49	VSE/I/P17	"	1.125	1.143	1.146	1.142	1.139
50	BFE/I/P17	"	2.500	2.567	2.568	2.566	2.562

Num	Location	Access	Nom Thk	7.0	14.0
57	BFW/O/S9	Snooper	2.125	2.156	2.157
58	BFW/O/S9		1.750	1.764	1.764
59	BFW/I/S9	"	2.125	2.153	2.148
60	BFW/I/S9	"	1.750	1.766	1.766
67	BFW/O/S18	"	2.125	2.166	2.176
68	BFW/O/S18	"	2.750	2.792	2.789
69	BFW/I/S18	"	2.125	2.184	2.180
70	BFW/I/S18	"	2.750	2.794	2.791

BFW/I/S2 = Bottom Flange West Side/Inside/Span 2   VSW/I/P8 = Vertical Stiffener/Inside/Pier 8

LS/O/S1 = Longitudinal Stiffener/Outside/Span 1

ULTRASONIC MEASUREMENTS

GRAPH	LOCATION	NOM THK	9/83	6/85	6/87	6/91
40	EW/I/S2	0.500	0.532	0.524	0.523	0.520
41	EW/I/S2	0.750	0.783	0.771	0.763	0.765
42	WW/I/S2	0.500	0.532	0.530	0.519	0.520
43	WW/I/S2	0.750	0.783	0.774	NO MEA	0.770
44	EW/I/P6	0.625	0.649	0.634	0.640	0.640
45	WW/I/P6	0.750	0.790	0.771	0.775	0.770
46	EW/I/P8	0.750	0.784	0.759	0.768	0.770
47	WW/I/P11	0.625	0.651	0.633	0.622	0.640
48	EW/I/P11	0.625	0.650	0.633	0.630	0.635
49	WW/I/P16	0.625	0.652	0.637	0.633	0.635
50	EW/I/P16	0.625	0.653	0.637	0.643	0.640
51	WW/I/P17	0.750	0.772	0.767	0.755	0.760
52	EW/I/P17	0.750	0.772	0.761	0.757	0.750

EW/I/P6 = EAST WEB/INSIDE/PIER 6 AND WW/I/S2 = WEST WEB/INSIDE/SPAN2

20. APPENDIX D

RELATIVE HUMIDITY DATA

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
1/1 - 1/2, '90	84	21	88
1/2 - 1/3	75	7	29
1/3 - 1/4	80	18	75
1/4 - 1/5	85	19	79
1/5 - 1/6	85	18	75
1/6 - 1/7	84	24	100
1/7 - 1/8	No Data	No Data	
1/8 - 1/9	No Data	No Data	
1/9 - 1/10	No Data	No Data	
1/10 - 1/11	85	24	100
1/11 - 1/12	85	24	100
1/12 - 1/13	80	24	100
1/13 - 1/14	83	24	100
1/14 - 1/15	77	23	96
1/15 - 1/16	80	19	79
1/16 - 1/17	83	17	71
1/17 - 1/18	74	17	71
1/18 - 1/19	87	16	67
1/19 - 1/20	79	21	88
1/20 - 1/21	86	17	71
1/21 - 1/22	87	20	83
1/22 - 1/23	84	19	79
1/23 - 1/24	78	8	33
1/24 - 1/25	87	19	79
1/25 - 1/26	82	21	88
1/26 - 1/27	67	6	25
1/27 - 1/28	79	13	54
1/28 - 1/29	77	14	58
1/29 - 1/30	89	23	96
1/30 - 1/31	86	17	71
1/31 - 2/1	86	19	79
2/1 - 2/2	86	17	71
2/2 - 2/3	85	19	79
2/3 - 2/4	75	16	67
2/4 - 2/5	86	18	75
2/5 - 2/6	69	12	50
2/6 - 2/7	73	18	75
2/7 - 2/8	85	24	100
2/8 - 2/9	87	22	92
2/9 - 2/10	86	17	71
2/10 - 2/11	83	23	96
2/11 - 2/12	70	8	33
2/12 - 2/13	No Data	No Data	

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
2/13 - 2/14	No Data	No Data	
2/14 - 2/15	57	2	8
2/15 - 2/16	89	18	75
2/16 - 2/17	90	24	100
2/17 - 2/18	88	24	100
2/18 - 2/19	69	16	67
2/19 - 2/20	89	15	63
2/20 - 2/21	88	22	92
2/21 - 2/22	88	17	71
2/22 - 2/23	88	16	67
2/23 - 2/24	88	15	63
2/24 - 2/25	88	14	58
2/25 - 2/26	87	17	71
2/26 - 2/27	84	22	92
2/27 - 2/28	86	20	83
2/28 - 3/1	79	23	96
3/1 - 3/2	89	24	100
3/2 - 3/3	87	24	100
3/3 - 3/4	84	20	83
3/4 - 3/5	85	23	96
3/5 - 3/6	77	15	63
3/6 - 3/7	No Data	No Data	
3/7 - 3/8	No Data	No Data	
3/8 - 3/9	75	15	63
3/9 - 3/10	89	17	71
3/10 - 3/11	82	16	67
3/11 - 3/12	75	16	67
3/12 - 3/13	84	15	63
3/13 - 3/14	66	15	63
3/14 - 3/15	85	18	75
3/15 - 3/16	89	17	71
3/16 - 3/17	80	20	83
3/17 - 3/18	87	19	79
3/18 - 3/19	85	14	58
3/19 - 3/20	61	6	25
3/20 - 3/21	87	16	67
3/21 - 3/22	71	8	33
3/22 - 3/23	89	18	75
3/23 - 3/24	82	15	63
3/24 - 3/25	80	15	63
3/25 - 3/26	94	19	79
3/26 - 3/27	77	13	54
3/27 - 3/28	87	16	67

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
3/28 - 3/29	88	15	63
3/29 - 3/30	87	16	67
3/30 - 3/31	87	18	75
3/31 - 4/1	89	17	71
4/1 - 4/2	89	16	67
4/2 - 4/3	68	5	21
4/3 - 4/4	87	10	42
4/4 - 4/5	80	16	67
4/5 - 4/6	79	21	88
4/6 - 4/7	72	21	88
4/7 - 4/8	79	24	100
4/8 - 4/9	87	17	71
4/9 - 4/10	78	13	54
4/10 - 4/11	85	10	42
4/11 - 4/12	78	12	50
4/12 - 4/13	81	10	42
4/13 - 4/14	82	8	33
4/14 - 4/15	81	16	67
4/15 - 4/16	77	24	100
4/16 - 4/17	84	24	100
4/17 - 4/18	84	24	100
4/18 - 4/19	77	22	92
4/19 - 4/20	86	22	92
4/20 - 4/21	80	18	75
4/21 - 4/22	76	17	71
4/22 - 4/23	89	21	88
4/23 - 4/24	68	12	50
4/24 - 4/25	No Data	No Data	
4/25 - 4/26	62	10	42
4/26 - 4/27	58	5	21
4/27 - 4/28	67	12	50
4/28 - 4/29	53	3	13
4/29 - 4/30	55	5	21
4/30 - 5/1	35	0	0
5/1 - 5/2	83	6	25
5/2 - 5/3	44	0	0
5/3 - 5/4	69	9	38
5/4 - 5/5	62	4	17
5/5 - 5/6	78	11	46
5/6 - 5/7	59	5	21
5/7 - 5/8	73	4	17
5/8 - 5/9	84	16	67
5/9 - 5/10	78	16	67

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
5/10 - 5/11	74	16	67
5/11 - 5/12	69	13	54
5/12 - 5/13	75	11	46
5/13 - 5/14	70	9	38
5/14 - 5/15	68	13	54
5/15 - 5/16	85	9	38
5/16 - 5/17	70	15	63
5/17 - 5/18	77	19	79
5/18 - 5/19	77	24	100
5/19 - 5/20	90	23	96
5/20 - 5/21	89	21	88
5/21 - 5/22	78	14	58
5/22 - 5/23	87	17	71
5/23 - 5/24	69	13	54
5/24 - 5/25	67	9	38
5/25 - 5/26	84	16	67
5/26 - 5/27	85	18	75
5/27 - 5/28	83	23	96
5/28 - 5/29	73	15	63
5/29 - 5/30	79	14	58
5/30 - 5/31	83	21	88
5/31 - 6/1	81	12	50
6/1 - 6/2	59	10	42
6/2 - 6/3	65	13	54
6/3 - 6/4	78	15	63
6/4 - 6/5	67	9	38
6/5 - 6/6	78	16	67
6/6 - 6/7	76	17	71
6/7 - 6/8	52	1	4
6/8 - 6/9	42	0	0
6/9 - 6/10	75	12	50
6/10 - 6/11	71	11	46
6/11 - 6/12	55	7	29
6/12 - 6/13	63	9	38
6/13 - 6/14	69	12	50
6/14 - 6/15	84	20	83
6/15 - 6/16	87	21	88
6/16 - 6/17	73	14	58
6/17 - 6/18	77	13	54
6/18 - 6/19	60	8	33
6/19 - 6/20	64	7	29
6/20 - 6/21	78	3	13
6/21 - 6/22	85	15	63

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
6/22 - 6/23	84	16	67
6/23 - 6/24	84	14	58
6/24 - 6/25	62	9	38
6/25 - 6/26	70	3	13
6/26 - 6/27	86	7	29
6/27 - 6/28	87	15	63
6/28 - 6/29	83	13	54
6/29 - 6/30	68	8	33
6/30 - 7/1	81	4	17
7/1 - 7/2	61	6	25
7/2 - 7/3	62	7	29
7/3 - 7/4	No Data	No Data	
7/4 - 7/5	No Data	No Data	
7/5 - 7/6	87	15	63
7/6 - 7/7	70	10	42
7/7 - 7/8	79	10	42
7/8 - 7/9	88	16	67
7/9 - 7/10	73	7	29
7/10 - 7/11	51	1	4
7/11 - 7/12	42	0	0
7/12 - 7/13	69	7	29
7/13 - 7/14	81	10	42
7/14 - 7/15	87	16	67
7/15 - 7/16	88	17	71
7/16 - 7/17	84	16	67
7/17 - 7/18	74	11	46
7/18 - 7/19	64	12	50
7/19 - 7/20	78	13	54
7/20 - 7/21	91	16	67
7/21 - 7/22	90	17	71
7/22 - 7/23	85	16	67
7/23 - 7/24	62	5	21
7/24 - 7/25	89	15	63
7/25 - 7/26	81	12	50
7/26 - 7/27	87	11	46
7/27 - 7/28	87	16	67
7/28 - 7/29	86	14	58
7/29 - 7/30	88	12	50
7/30 - 7/31	88	13	54
7/31 - 8/1	89	14	58
8/1 - 8/2	88	15	63
8/2 - 8/3	87	No Data	
8/3 - 8/4	85	No Data	

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
8/4 - 8/5	83	No Data	
8/5 - 8/6	No Data	No Data	
8/6 - 8/7	79	No Data	
8/7 - 8/8	No Data	No Data	
8/8 - 8/9	66	17	71
8/9 - 8/10	86	11	46
8/10 - 8/11	82	No Data	
8/11 - 8/12	89	No Data	
8/12 - 8/13	77	No Data	
8/13 - 8/14	74	No Data	
8/14 - 8/15	81	No Data	
8/15 - 8/16	84	21	88
8/16 - 8/17	86	19	79
8/17 - 8/18	79	20	83
8/18 - 8/19	80	17	71
8/19 - 8/20	82	No Data	
8/20 - 8/21	85	No Data	
8/21 - 8/22	No Data	No Data	
8/22 - 8/23	80	10	42
8/23 - 8/24	84	13	54
8/24 - 8/25	82	24	100
8/25 - 8/26	84	18	75
8/26 - 8/27	82	No Data	
8/27 - 8/28	93	No Data	
8/28 - 8/29	No Data	No Data	
8/29 - 8/30	84	16	67
8/30 - 8/31	73	15	63
8/31 - 9/1	72	No Data	
9/1 - 9/2	83	No Data	
9/2 - 9/3	69	No Data	
9/3 - 9/4	83	14	58
9/4 - 9/5	73	18	75
9/5 - 9/6	78	14	58
9/6 - 9/7	65	No Data	
9/7 - 9/8	No Data	No Data	
9/8 - 9/9	74	No Data	
9/9 - 9/10	89	No Data	
9/10 - 9/11	81	No Data	
9/11 - 9/12	No Data	No Data	
9/12 - 9/13	75	No Data	
9/13 - 9/14	86	No Data	
9/14 - 9/15	69	17	71
9/15 - 9/16	71	15	63

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
9/16 - 9/17	77	12	50
9/17 - 9/18	79	13	54
9/18 - 9/19	No Data	No Data	
9/19 - 9/20	No Data	No Data	
9/20 - 9/21	65	9	38
9/21 - 9/22	86	18	75
9/22 - 9/23	83	13	54
9/23 - 9/24	80	17	71
9/24 - 9/25	80	17	71
9/25 - 9/26	84	20	83
9/26 - 9/27	77	No Data	
9/27 - 9/28	82	15	63
9/28 - 9/29	90	15	63
9/29 - 9/30	85	13	54
9/30 - 10/1	87	13	54
10/1 - 10/2	64	4	17
10/2 - 10/3	No Data	No Data	
10/3 - 10/4	71	10	42
10/4 - 10/5	81	20	83
10/5 - 10/6	73	16	67
10/6 - 10/7	78	6	25
10/7 - 10/8	21	0	0
10/8 - 10/9	69	7	29
10/9 - 10/10	74	10	42
10/10 - 10/11	67	5	21
10/11 - 10/12	83	8	33
10/12 - 10/13	72	9	38
10/13 - 10/14	75	12	50
10/14 - 10/15	72	10	42
10/15 - 10/16	84	17	71
10/16 - 10/17	84	13	54
10/17 - 10/18	84	No Data	
10/18 - 10/19	91	19	79
10/19 - 10/20	45	0	0
10/20 - 10/21	70	8	33
10/21 - 10/22	66	3	13
10/22 - 10/23	82	10	42
10/23 - 10/24	87	13	54
10/24 - 10/25	No Data	No Data	
10/25 - 10/26	87	12	50
10/26 - 10/27	86	12	50
10/27 - 10/28	74	15	63
10/28 - 10/29	82	18	75

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
10/29 - 10/30	84	19	79
10/30 - 10/31	84	No Data	
10/31 - 11/1	74	14	58
11/1 - 11/2	36	0	0
11/2 - 11/3	No Data	No Data	
11/3 - 11/4	79	No Data	
11/4 - 11/5	85	No Data	
11/5 - 11/6	61	4	17
11/6 - 11/7	No Data	No Data	
11/7 - 11/8	74	6	25
11/8 - 11/9	83	No Data	
11/9 - 11/10	88	No Data	
11/10 - 11/11	92	No Data	
11/11 - 11/12	83	No Data	
11/12 - 11/13	80	No Data	
11/13 - 11/14	88	17	71
11/14 - 11/15	90	17	71
11/15 - 11/16	91	No Data	
11/16 - 11/17	78	22	92
11/17 - 11/18	77	19	79
11/18 - 11/19	80	24	100
11/19 - 11/20	77	21	88
11/20 - 11/21	89	15	63
11/21 - 11/22	87	16	67
11/22 - 11/23	89	No Data	
11/23 - 11/24	87	No Data	
11/24 - 11/25	89	No Data	
11/25 - 11/26	90	20	83
11/26 - 11/27	77	8	33
11/27 - 11/28	89	17	71
11/28 - 11/29	89	19	79
11/29 - 11/30	85	15	63
11/30 - 12/1	89	16	67
12/1 - 12/2	79	No Data	
12/2 - 12/3	89	No Data	
12/3 - 12/4	81	19	79
12/4 - 12/5	67	9	38
12/5 - 12/6	81	No Data	
12/6 - 12/7	82	14	58
12/7 - 12/8	81	14	58
12/8 - 12/9	83	16	67
12/9 - 12/10	80	17	71
12/10 - 12/11	83	24	100

Date	High	Duration Above 50% (hrs)	Percent of Time Above 50%
12/11 - 12/12	81	No Data	
12/12 - 12/13	83	21	88
12/13 - 12/14	83	18	75
12/14 - 12/15	79	24	100
12/15 - 12/16	79	22	92
12/16 - 12/17	79	17	71
12/17 - 12/18	81	21	88
12/18 - 12/19	79	No Data	
12/19 - 12/20	65	15	63
12/20 - 12/21	44	0	0
12/21 - 12/22	No Data	No Data	
12/22 - 12/23	78	11	46
12/23 - 12/24	67	3	13
12/24 - 12/25	78	No Data	
12/25 - 12/26	No Data	No Data	
12/26 - 12/27	83	17	71
12/27 - 12/28	83	16	67
12/28 - 12/29	83	11	46
12/29 - 12/30	28	0	0
12/30 - 12/31	60	7	29
12/31 - 1/1, '91	85	16	67
AVG. VALUES	78	14.3	60